Homathko Development

Generation

Preliminary Thermal Regime Study of the Lower Homathko River

B.C. Hydro

Hydroelectric Generation Projects Division

Report No. H1723

October

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HOMATHKO DEVELOPMENT

GENERATION

PRELIMINARY THERMAL REGIME STUDY OF THE LOWER HOMATHKO RIVER

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"This report contains information available as of March 1984. By September 1984 all Homathko Development studies and data collection programs had been suspended. Some information in this report may be incomplete and is subject to amendment as a result of future studies".

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HOMATHKO DEVELOPMENT

PRELIMINARY THERMAL REGIME STUDY
OF THE
LOWER HOMATHKO RIVER

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The Data Appendices are published in Report H 1733.[1] The Table of Contents only are reproduced on the following pages. The Appendices are a compilation of data only and contain no interpretation.

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SYNOPSIS

The Homathko River has been recognized for many years as having a potential for hydroelectric development. In its course from Tatlayoko Lake through the Coast Range Mountains to Bute Inlet the river drops 827 m. An engineering feasibility study of potential hydroelectric developments was begun in 1981 and has identified that for all development alternatives the most downstream damsite would be at Waddington Canyon about 57 km upstream from the mouth of the Homathko River.

Concurrent with the engineering investigations, preliminary environmental studies of the Homathko River basin were conducted. The proposed regulation of the Homathko River would modify the thermal regime by reservoir impoundment and flow regulation. This could have impacts on the fish species which utilize the lower Homathko River's mainstem, back channels and tributaries. This study was undertaken to document the natural thermal regime and to provide a preliminary estimate of the range of changes to that regime that could be expected under regulation.

During the course of the study a program of budget restraint was introduced which resulted in a decision to suspend work and wrap up the studies underway. All major items in the Terms of Reference have been addressed with the exception of a study of the effect of short term load fluctuations on temperature, discharge and flow depth. The wrap-up studies concentrated on the provision of 1) the results from computer simulations of the natural and regulated thermal regimes for 1983, 2) a series of degree-day accumulations throughout the winter and 3) an inventory of water temperature data.

This report was originally intended to provide the basis for further investigations by other disciplines concurrent with further investigation of the thermal regime. As further studies have been postponed indefinitely, it is concluded that the present data base of 1 year is inadequate for studies providing the basis for the Preliminary Environmental Assessment. For such a level of study a minimum data base of 3 years is recommended.

The analysis of temperatures under the proposed future operating conditions for the Homathko Projects was made for three alternative locations of the Waddington Canyon tailrace exit:

1. At the damsite.
2. 4.5 km downstream (2.7 km Tailrace Tunnel).
3. 21.5 km downstream (13.2 km Tailrace Tunnel).

On the basis of reservoir temperature model studies for the proposed Iskut and Stikine reservoirs it was assumed that water from the Waddington Canyon Project would be released at temperatures close to the natural average without the need for special multiport withdrawal facilities. The downstream temperatures resulting from this assumption comprised the reference case around which sensitivity tests were conducted using release temperatures of plus and minus 2°C.

The tentative conclusion from this study is that for the reference case there would be only minor temperature differences from the natural condition at points downstream of the three alternative tailrace exits. In the river reaches bypassed by the tailrace tunnel the river temperatures would be 3 to 4°C colder in mid-summer than under natural conditions. For Waddington Canyon releases 2°C above and below the assumed temperatures for the reference case it was found that the downstream temperature differences remained approximately constant at ±2°C for the first 11.5 km downstream of Waddington Canyon and then tended toward the reference case.

It is recommended that in future investigations of the thermal regime of the lower Homathko River, a study of Waddington Canyon Reservoir release temperatures be a priority unless the range of downstream temperatures indicated would not result in a potential environmental problem. A study of the interaction of surface streamflows and groundwater in side channels used for spawning has also been identified as a priority in future studies. A need for further collection of water temperature and meteorological data before the resumption of future office studies has been identified. It is recommended that the need for an investigation into the effect of rapid load fluctuations be reviewed during future studies.

PRELIMINARY

1.0 INTRODUCTION

The Homathko River has been recognized for many years as having a potential for hydroelectric development. In its course from Tatlayoko Lake through the Coast Range Mountains to Bute Inlet the river drops 827 m. An engineering feasibility study[1] of potential hydroelectric developments was begun in 1981 and has identified that for all development alternatives the most downstream damsite would be at Waddington Canyon about 57 km upstream from the mouth of the Homathko River.

The proposed dams on the Homathko River at and above Waddington Canyon would modify the hydrologic and thermal regimes of the lower Homathko River below Waddington Canyon. This modification of the thermal regime by reservoir impoundment and flow regulation could lead to possible impacts on the fish species which utilize the lower Homathko River. Water temperature is an important factor in the incubation rate, growth rate and survival of juvenile salmonids and in the initiation of upstream migration of adult salmonids. Therefore, the Hydraulics Section of the Hydroelectric Generation Projects Division (HGPD) was given an assignment by the Environmental and Socio-Economic Services Department (ESS) "to determine the nature of the natural thermal regime of the lower Homathko and provide a preliminary estimate of the range of changes (to the thermal regime) to be expected under regulation."

The principal results of this study were transmitted to ESS via an Interim Report on 16 March 1984. This final report more fully documents the study results and methodology and supersedes and replaces the Interim Report. A volume of Data Appendices entitled "Compilation of Water Temperature and Meteorological Data"[2] has been prepared as Report No. H 1733 to compile the water temperature and meteorological data collected for the Preliminary Thermal Regime Study.

This study was conducted under the attached Terms of Reference (TOR) of 28 July 1983. During the course of this study the imposition of budgetary restraints resulted in a management decision to suspend work and wrap up studies underway. Following this decision it was jointly agreed by ESS and HGPD to concentrate on:

1. The provision of simulation results of the natural and regulated water temperature regimes for the calendar year 1983, (TOR Section 4.0(a) Item 4 and (b) Item 2).

2. The provision of a series of degree-day accumulations throughout a complete winter cycle. (TOR Section 4.0(b) Item 4.)

3. The provision of an inventory of all water temperature data collected. (TOR Section 4.0(a) Items 1 and 2.)

Other items in the Terms of Reference are discussed briefly with the exception of Section 4.0(b) Item 3 concerning the effects of short term load fluctuations on temperature, discharge and depth. This item has been omitted as a result of the budgetary restraint program.

2.0 MATHEMATICAL MODEL

Under the Terms of Reference for this study, the water temperatures for 1983 under natural and regulated flow conditions were to be simulated throughout the 57 km length of the lower Homathko River. This requirement, to simulate continually changing flows and water temperatures in a long river reach of variable cross section under naturally varying meteorological conditions, could only be met by using an unsteady flow and water temperature model. The model chosen was the "DUPSERT" model developed by HGPD for modelling water temperatures under similar conditions on the Kootenay Diversion Project.[3]

The model is an unsteady flow and temperature model in which the hydraulic properties of the river system are computed by the first portion of the model and then a surface heat exchange analysis is performed by the second portion using the previously computed hydraulic properties. The unsteady temperature computations were made using the hydraulic properties calculated at the various designated river cross sections. This type of model in which the unsteady flow and temperature models are coupled together is referred to as a "coupled" hydrodynamics and temperature model. The "DUPSERT" model is fully described in HGPD Report No. H 1360 - Water Temperature Regime Studies, Kootenay River Diversion Project[3] and in an ASCE paper "Modelling of Unsteady-Flow Water Temperatures"[4] which is enclosed in Attachment 3.

3.0 DATA

This section briefly describes the data used in this study, where it was obtained and/or how it was processed to conform to the needs of this study. A separate Data Appendix entitled "Compilation of Water Temperature and Meteorological Data" is being published as Report No. H 1733 to collect in one place all field water temperatures and meteorological data collected during this study.

(a) Cross Section Data

(i) Natural Conditions

The cross-sectional data for the lower Homathko River were obtained from the report "Homathko Development - 1983 Surveys - Vol. 1 Lower Homathko Section"[5] by B.C. Hydro, Route Engineering. The report presents the results of their 1983 field surveys of 20 cross sections in the lower Homathko River. These cross sections were selected to meet the

requirements of the Preliminary Thermal Regime, Preliminary Sediment Regime and Preliminary Fluvial Morphology Studies.

As a result of the imposition of budget restraint and the curtailment of certain aspects of the study, a very simple representation of the lower Homathko River was found adequate for the reduced level of study as explained in Section 4.0(a).

(ii) Post-Project Conditions

The same cross sections and riverbed slopes were used in both pre- and post-project analyses. The Homathko River is described in the Preliminary Fluvial Morphology Report[6] as an active gravel bed river. Changes in bed invert of 3.0 m and 1.2 m were observed at cross sections XLH 70 and XLH 140, respectively, during the passage of the 1983 summer freshet. Both of these cross sections are at constrictions and thus exhibit a greater than normal range of movement but do graphically illustrate how active the Homathko can be. Thus the use of the same cross section to approximate both the pre- and post-project conditions was a reasonable assumption at this stage of study.

(b) Water Levels and Discharge Data

(i) Natural Conditions

Hydraulic computations were based on water levels and discharges obtained from the Water Survey of Canada (WSC) stations "Homathko River at Tragedy Canyon" and "Homathko River at the Mouth". The Tragedy Canyon station is only a few kilometres upstream of the mouth of Waddington Canyon and the runoff from the intervening drainage area between the station and Waddington Canyon is insignificant. For the WSC station

"At the Mouth" the water level gauge is near cross section XLH 30 but the discharges are measured at XLH 10 downstream (Fig. 1). There is only a 2.7 percent difference in drainage area between XLH 10 and XLH 30. In this study the usual practice of assigning the discharge to the location of the water level recorder was followed. Under ideal conditions discharge measurements have an accuracy of 5 percent. XLH 10 is within the tidal zone and thus measurements there can be subject to additional errors. Thus the assignment of discharges to XLH 30 should not introduce any significant error.

Tributary flows were initially estimated on the basis of drainage area. After comparing the routed flows with the observed spot discharge measurements at XLH 140 and XLH 70 and comparing the routed flows with the recorded discharge at the WSC station "At the Mouth", individual tributary flows above Scar Creek (Fig. 1) were increased up to 10 percent while tributary flows downstream of Scar Creek were decreased 3.6 percent. The total inflow from the tributaries remained unchanged as a result of this adjustment. This adjustment was made empirically by matching the observed and computed hydrographs at these three gauging stations. No direct correlation incorporating the percent of glacier covered area or other physical factors was attempted. The comparison between routed flows and observed discharges is further discussed in Section 4.0(a) - Verification and Calibration.

Water levels were collected by a joint HGPD-ESS field crew on a weekly or monthly basis at 12 staff gauges on the mainstem and at 4 staff gauge locations on tributaries. Miscellaneous discharge measurements were taken on a regular basis during the summer of 1983 at XLH 70 and XLH 140. A summary of water level readings and discharge measurements has been published

by the Hydrology Section of HGPD as part of their Preliminary Watershed Hydrology Study[7] for ESS.

(ii) Post-Project Conditions

For the post-project case, the regulated outflows from Waddington Canyon were supplied by B.C. Hydro (1984)[8] from routing studies.

(c) Water Temperatures

(i) Natural Temperatures

The water temperature data for this study of the lower Homathko were obtained from two WSC stations as preliminary information and from eight Ryan thermographs installed by B.C. Hydro:

WSC Stations:

Homathko River at the Mouth (XLH 30)
Homathko River at Tragedy Canyon

B.C. Hydro Ryan Thermographs on the mainstem:

Homathko River at XLH 70
Homathko River below XLH 120 in back channel ("20 Mile")
Homathko River at XLH 140
Homathko River at XLH 170
Homathko River at XH 300

B.C. Hydro Ryan Thermographs on tributaries:

Jewakwa River
Brew Creek
Scar Creek
Klattasine Creek (station destroyed by flood waters - no useful data)

Fig. 2 shows the period of record for the B.C. Hydro stations actually used in this study. The record of temperature data

from the WSC station "At the Mouth" was complete from mid-April 1983 to the end of December 1983. However, for a short period in mid-summer the preliminary data were obviously in error. This is discussed in more detail later in this section. At Tragedy Canyon there were several weeks of missing data from September to November. Four B.C. Hydro thermographs at "20 Mile", XLH 140, Jewakwa River and Scar Creek were operated over the winter of 1982/83 but the charts were not received in time for use in this study. These data have been included in the Data Appendices.[2]

Data from all stations have been collected until 31 March 1984. All water temperature data have been compiled and published in the Data Appendices.

Water temperatures at XH 300 are required as the starting upstream temperatures in the model. Thus the water temperature records for the WSC's nearby Tragedy Canyon station were combined with the record at the base station - XH 300. During a field trip to the Homathko on 17 October 1983, D.E. Cass and R. Chau noted[9] that the station at XH 300 was, at the existing low flow, in a back eddy and recording a water temperature 0.4°C higher than in the main river. No adjustment to the temperature record at XH 300 was made for this study as the correction is small and may not be the same during the night for this period. On this October trip the mainstream temperatures at XH 300 and Tragedy Canyon were found to be within 0.1°C of each other. During mid-August 1983 there were anomalies in both the record at XH 300 and Tragedy Canyon that originated at the time of chart changes at both stations. The data from XH 300 were used for the computer runs without adjustment. This anomaly shows up as a temperature spike in mid-August on the natural curve (Fig. 12). The magnitude of this spike was later found to be erroneous. The correct

maximum temperature reached during this period was 9.0°C on 14 August 1983. This erroneous spike can be followed through the Homathko system on Figs. 4 to 7. The model input data and the temperatures at XH 300 in the Data Appendix have been corrected but the computer analysis was not rerun due to budget restraint. In any case, the duration of the spike was only a few days and did not affect the overall analysis.

The WSC station at XLH 30 "Homathko River at the Mouth" is the most downstream station recording temperature. However, during July 1983 the WSC preliminary data showed a series of extreme temperature spikes that were obviously not representative of Homathko River temperatures. During the visit by R. Chau and D.E. Cass on 17 October 1983, it was noted that at the existing low flow the thermograph was in a pool of stagnant water with a temperature of 1°C higher than that of the river at 5:15 p.m. on a cloudy day. This pool was connected to the river at the downstream end but separated from the river on the sides and upstream end by a 0.5 m bar. Obviously, during the low flow months the temperature recorded at this station was not representative of Homathko River temperatures.

The tributary temperatures used in this study are those of Brew Creek. Partial temperature records were available on Brew Creek, Scar Creek and the Jewakwa River. Brew Creek temperatures were warmer than those for the Jewakwa River and cooler than those for Scar Creek and thus represented an average of the available tributary temperatures. Brew Creek also had the longest available period of record (June to November 1983). Brew Creek temperatures were therefore adopted for use on all tributaries. In December 1983 the missing Brew Creek temperatures were filled in by correlation with the Jewakwa River. The missing period of record on Brew

Creek from January to May 1983 was filled in by correlation with the Homathko River at XH 300.

Later the recorded data for the winter of 1983/84 was received and compiled for the Data Appendix. Comparison of the observed and correlated data shows that for the winter months of December, January and February the correlated temperatures were 2 to 3°C too high. This is unfortunate but will not have significantly affected the mainstem temperatures computed by the model. Tributary flows were low and once entering the main river would have cooled almost immediately to the river temperature by dilution and surface heat exchange.

(ii) Post-Project Temperatures

In order to start the analysis of post-project temperatures, the Waddington Canyon release temperatures were required. Under Section 4.0(b) Item 1 of the Terms of Reference, average and possible extreme conditions of the Waddington Canyon release temperatures were to be provided. The "mid-range" release temperatures on Fig. 11 were estimated[10] as the approximate moving average of the observed 1983 daily mean temperatures at XH 300 on Fig. 12, except in mid-winter. December and January releases were estimated as 2°C on the basis of reservoir temperature modelling studies[10,11] of the Iskut Canyon Project.

This assumption about the release temperatures was based on the experience gained from reservoir temperature modelling studies[10,11] of the Iskut and Stikine Canyon Projects. The Iskut Canyon studies showed that, except in mid-winter, release temperatures would normally fall within the band width of historical temperatures without the need for a selective withdrawal facility. Only normal operating procedures were

assumed in this study. Model studies for the Stikine Canyon Project found that during the winter the selective withdrawal facilities would decrease release temperatures by only 0.5°C to 1.0°C when compared with a standard power intake which would release water at 4°C above the natural temperatures. During the summer selective withdrawal facilities on the Stikine Canyon Project would partially prevent cooling of water temperatures by the 3 to 5°C expected with a standard power intake. However, on the Stikine, cooling of summer temperatues is not a major concern. The main requirement for selective withdrawal facilities on northern reservoirs is to lower the temperature of winter releases. Therefore selective withdrawal facilities were not thought to be useful for either the Iskut or Stikine Canyon Projects. Thus it has been assumed that they would not be effective for the Waddington Canyon Project and the release temperatures were estimated on the basis of the Iskut Canyon experience assuming a standard power intake.

As the effects of a variation from the typical release temperatures may be significant, the likely band width of release temperatures was investigated. From the data reported in Iskut-Stikine reservoir modelling studies[11] it was noted that the Iskut River at the Iskut Canyon site and the Homathko River at Tragedy Canyon had similar natural temperature regimes. Two years of data were available for the Iskut and one for the Homathko. Both rivers had maximum daily summer temperatures around 8°C. The band width of daily fluctuations was 3° to 5°C for the Iskut and 2.5° to 3°C for the Homathko during spring, summer and fall. Both dam sites were within the Coast Range and the rivers were fed from a mixture of dry interior sub-basins and wetter coastal-interior sub-basins covered heavily with glaciers.

Records from other large northern rivers; such as, the Stikine River at Site Z and the Peace River at Hudson Hope (before regulation), that are entirely from the interior climate zones were examined. Such rivers tend to have warmer summer temperatures in the 13° to 15°C range with wider band widths of 3° to 6°C. However, on the basis of the records available and the presence of significant glacier covered areas (13 percent),[7] the release temperatures from Waddington Canyon were estimated to have a 4°C band width. Thus the thermal regime of the lower Homathko was analyzed for cases with an "average" release temperature and with release temperatures 2°C above and below the "average" release temperatures.

The "alternative" schedule of Waddington release temperatures shown in red on Fig. 12 was not used in the analyses but is discussed in Section 5.0(a).

(d) Meteorological Data

(i) Climatic Data

A meteorological station at the confluence of Brew Creek and the Homathko has been operated since November 1982. This station records dry bulb air temperature, relative humidity and wind speed and direction. Dew point temperatures were computed from these basic data. Unfortunately at the time the analyses for the Thermal Regime Study were made only data from November 1982 to 16 June 1983 had been processed. During this period there were minor gaps of 1 to 3 weeks in some parameters.

For the remainder of the year, the values for air temperature, dew point and wind speed were estimated by correlating these parameters on an annual basis with the Atmospheric Environment

Service's (AES) station at Powell River. The correlation coefficients (r^2) were 0.84 for air temperature, 0.79 for dew point and 0.08 for wind speed. Data for August 1983 were not available at Powell River so data from the AES station at Campbell River were used to complete the record at Powell River. These correlations are poor and it would have been preferable to have been able to use the data collected at the Brew Creek meteorological station.

(ii) Shortwave Solar Radiation

A pyranometer for measuring short wave solar radiation was operated in the lower Homathko basin at the Forest Service's Scar Creek meteorological station during the summer of 1983. As most of the observed solar radiation data had not been processed, it was decided to use calculated values for solar radiation modified by cloud cover values recorded at the AES station in Powell River.

The clear sky solar radiation was calculated as radiation absorbed at the water surface using the computer program SOLRAD developed by L.J. Parmley of HGPD's Hydrology Section for use on Liard-Mackenzie water temperature studies. This program is based on the work of Raphael[12] as systematized by Thackston and Parker.[13]

Before adopting the method used by SOLRAD a comparison was made between the SOLRAD estimates for the year 1977 at the Vancouver-UBC station and the observed solar radiation. As a result of this comparison it was decided to increase SOLRAD estimates by 2 percent. The underestimation of the observed solar radiation by the computed varied seasonally from an average of approximately zero in August to 25 to 30 percent in January and December. Initially, it was decided to adopt a

constant correction factor weighted heavily toward the summer months when solar radiation is a maximum and has the greatest influence on water temperatures. When the verification tests, using this constant correction factor, showed good agreement with the observed water temperature throughout the whole year, this constant correction factor was adopted. For use in the lower Homathko River basin a shading correction of 15 percent was applied on the basis of a shading diagram drawn up for Scar Creek. Thus a net correction of -13 percent was applied to the calculated absorbed clear sky solar radiation.

4.0 VERIFICATION AND CALIBRATION

(a) Hydraulic Routing

As described in Section 2.0 on the Mathematical Model, the model used in this thermal study was a coupled hydrodynamic and temperature model. A verification test of the hydraulic portion of the model was made to ensure that it was correctly routing flows and that tributary flows had been estimated and proportioned along the river length in a sufficiently accurate manner. The comparison plot of the computed and observed hydrographs on Fig. 3 shows very good agreement.

As a further check on the accuracy of the routed daily mean discharges, a comparison was made with seven spot discharge measurements at each of two stations in the middle reaches of the lower Homathko; XLH 140 and XLH 70. This showed agreement within a range of -25 percent to +25 percent at XLH 140 and 0 to +25 percent at XLH 70 using the ratio of the computed daily flow over the spot discharge measurement. The average percentage differences at XLH 140 and XLH 70 were +1 percent and +15 percent, respectively. Diurnal variations in discharge of 5 to 15 percent between the

daily maximum and minimum at Tragedy Canyon and 4 to 7 percent at "the Mouth" were common. In light of these diurnal variations the comparison between the routed daily mean discharges and the spot measurements at XLH 140 and XLH 70 is satisfactory.

While attempting to make this verification run using all the cross section and slope data referenced in Section 3.0(a), it was found that the differences between cross sections was such that a large number of transition sections would be required to obtain a realistic and relatively smooth hydraulic profile. As the effort and cost of inserting these transitions would have been considerable and as the temperature portion of the model required a realistic hydraulic profile to ensure numerical stability, a trial computation was made using XLH 30 as a single typical cross section. As this gave a very close comparison between the measured and routed discharges, it was decided to conduct the temperature modelling using this typical cross section. The actual bed slopes between the 20 surveyed cross sections were used with minor adjustments except in the upper reaches toward Waddington Canyon. There the slope was flattened considerably to prevent supercritical flow occurring in the model.

The good comparison for routed discharges indicates that, when used with the slopes chosen, the typical cross section yielded a channel conveyance that is an effective representation of the overall average conveyance throughout the whole reach of the Lower Homathko. This does not mean that water depth computed with this model was representative of the actual depth for a particular reach. In fact, although in some reaches the computed depths were within 0 to -0.5 m of the observed depths, there were other reaches were the computed depths differ by as much as +2.5 m. The model could be improved to yield results matching both the observed depth and discharge at local points by the use of the measured cross

sectional data from the field survey plus intermediate sections from the aerial photography.

Such a refinement was the original intention for two reasons. First, there were many changes of regime type between braided, split and meandering channels and many cross-sectional changes within one type of channel. Thus there was concern that the depth and the water surface width would not be known accurately enough for the surface heat exchange calculations. The second reason was that the Terms of Reference required an examination of changes to the rate and magnitude of flow and stage variations between the natural and regulated conditions. This could not be done in the model without a more detailed representation of the river channel geometry. Thus, as part of the field program in support of the preliminary studies of the thermal regime, sediment regime and fluvial morphology, 20 cross sections in the 57 km length of the lower Homathko River were surveyed and the aerial photo coverage improved.

However, the early model runs showed that water temperatures on the Homathko could be adequately represented with the use of a single typical cross section. After the decision to suspend Homathko studies, it was decided that an examination of changes in stage and flow variation was no longer warranted. Thus under the changed circumstance there was no longer any reason to refine the model by incorporating the rest of the available cross-sectional data.

The comparison plot in Fig. 3 is based on the results of routing with a daily time step. As the travel time for flows passing through the lower Homathko is very short, a test was made with an hourly time step to ensure that the hydraulic routing results were not significantly different.

(b) Water Temperature Analysis

Figs. 4 to 7 present the results of the comparisons made between the observed and computed natural temperatures on the lower Homathko River for 1983 for verification of the computer model.

(i) Observed 1983 Water Temperatures

A comparison of the observed temperatures at Stations XH 300, XLH 170, XLH 140, XLH 70 on Fig. 8 and in Tables 2 and 3 shows that the daily average temperature tended in general to increase by 0.0° to 1.5°C from upstream (XH 300) to downstream (XLH 70). The temperature between XH 300 and XLH 140 (Scar Creek) almost always increased with the larger differences occurring in late June and in late August through early September. During July the heavy glacial melt often resulted in a 1° to 1.5°C fall in temperature between XLH 140 and XLH 70.

A small temperature increase in the downstream direction between Waddington Canyon and XLH 70 was also observed during three longitudinal field profiles on 5 July 1983, 17 to 18 August 1983 and 17 October 1983. The results of these profiles are summarized in Table 3. As there were significant diurnal fluctuations, the temperatures at the key stations have been adjusted using the recorded hourly data.

On the days on which the field temperature profiles were conducted there was a 90 to 120 percent increase in the daily discharge between the two WSC stations at "Tragedy Canyon" and "At the Mouth". This increase in discharge came from tributaries that were 1° to 4°C cooler than the mainstem. Despite this increase in discharge from cold tributaries, there were small but consistent increases in temperature from Waddington

Canyon to XLH 70 on the days these profiles were taken. Between XLH 70 and XLH 30 the temperature dropped due to the cold inflows from the Jewakwa and Heakamie rivers. The temperature rise to XLH 70 was indicative of significant net heat input from surface heat exchange. The short travel time prevented a large increase in temperature but surface heat exchange was nonetheless a significant process.

An examination of the diurnal temperature fluctuations also illustrated the significance of surface heat exchange to water temperatures. From Fig. 9 it can be seen that at XH 300 the diurnal fluctuations in discharge and temperature were almost exactly in-phase. In Fig. 10 the discharge at the WSC station "At the Mouth" is plotted alongside the temperature record at XLH 70 which is 10 km upstream. Although the Heakamie and Jewakwa rivers join the Homathko between these points the diurnal trends in discharge at XLH 70 should be similar to those "At the Mouth". At XLH 70 the diurnal trends in discharge and temperature were no longer in-phase. At XLH 70 the diurnal temperature fluctuations peaked between 18:00 and 20:00 hours, as at XH 300. However, at XLH 70 the discharge peaks occurred 3 to 4 hours later than at XH 300. The maximum water temperature at both stations occurred during periods of rising or maximum discharge. At both stations the temperature fluctuations appeared to have been directly driven by the diurnal variation in solar energy input. The timing of the temperature fluctuations was almost independent of the variations in discharge.

(ii) Observed vs Computed Natural Temperatures

The verification runs show that in general the model underestimated the observed temperatures by 0° to 3°C at stations XLH 140, 20 Mile (XLH 120), and XLH 70. The agreement between

the computed and observed temperatures was better in the upstream reaches for reasons which will be discussed in the following paragraphs. In general the agreement throughout the lower Homathko was between 1 and 2°C and the shape of the computed trace followed the recorded trace very well.

The agreement between the computed and observed temperatures at the individual stations is now discussed. At XLH 30 Fig. 7 shows higher than normal spring and fall tempratures as a result of the recorder being in a stagnant pool in the low flow months. As discussed in Section 3.0(c)(ii), this was also noted during a field visit of 17 October 1983.

The two temperature spikes in the computed traces between May and June and between 5 to 15 August were the result of errors in input data. The May-June spike is especially obvious on Fig. 7 but is present in all cases. It resulted from the tributary inflows for one day being mistakenly given a negative sign. As both spikes are of short duration they will not affect the overall results. As a result of budget restraint the corrected cases were not run. However, the input data have been corrected so that these errors will be eliminated from future runs.

A comparison of the computed temperatures at the various stations showed that there was a decrease in the daily average water temperature from upstream to downstream. This temperature drop varied from a maximum of 2° in midsummer to nearly zero in winter. This small drop in the computed temperature from upstream to downstream was not in accordance with the observed small increase in temperature over the lower Homathko basin. This discrepancy with the observed longitudinal temperature profile and the underestimation of the "at station" temperatures were both minor. Both were principally

the result of an underestimation of the solar input. A small portion of the error may have resulted from the use of out-of-basin meteorological data, the assumption of a uniform tributary temperature and the use of a single typical cross section.

While acknowledging the presence of minor discrepancies the important consideration for comparison of pre- and post-project temperatures is that the same trend to underestimate water temperatures would be present in both the computed natural and computed post-project temperatures. Thus computed natural temperatures instead of the observed ones were used in the pre- versus post-project comparisons to ensure that the comparisons were made on the same basis and would yield realistic differences. The agreement obtained in the verification tests was satisfactory and showed that the model used was more than adequate to provide realistic pre- versus post-project comparisons. If improvements were made to the solar radiation function, if the Brew Creek meteorological data were used, if more cross sections were inserted to refine the model or if a more accurate representation of tributary temperatures were used, the verification comparisons would show small improvements but there would be no significant change in the pre- versus post-project comparisons.

Thus a satisfactory thermal regime model was made operational using only one typical cross section and approximating the vertical survey control data. This model was found to be sufficiently accurate for routing flows but not for estimating the rate and magnitude of stage variations at intermediate points. This does not mean that a thermal regime model on other rivers could be successfully constructed with such a minimum of field data. It does, however, point out that there is a distinct possibility of substantial savings in field

survey programs if limited preliminary field and office studies could be started a year in advance of the main program. Such preliminary studies would require water level, discharge and water temperature data at a limited number of key points (2 or 3) with which to do sensitivity studies on the effect of variations in cross section, river slope, tributary temperatures and discharges, and meteorological parameters.

5.0 POST-PROJECT TEMPERATURES

(a) General

The post-project water temperatures were computed assuming that the net effect on water temperatures of river regime changes on the lower Homathko would not be significant enough to seriously affect the results. (See Section 3.0(c)(ii).) Thus the same river cross sections were used for the analysis of both natural and post-project temperatures.

The analysis of post-project temperatures in the lower Homathko has been made for three alternative tailrace arrangements for the Waddington Canyon Project:

1. tailrace at damsite;
2. 2.7 km tailrace tunnel (exiting at XLH 155); and
3. 13.2 km tailrace tunnel (exiting 2.6 km upstream of XLH 90).

The 2.7 km tailrace tunnel alternative has been adopted as the base case in the current engineering studies. The other two cases represent the limits of likely tailrace tunnel exit locations. By analyzing these three cases the range of effects on the thermal regime of changing tailrace locations has been covered.

The post-project temperatures were analyzed assuming a "mid-range" Waddington Canyon release temperature. In order to indicate the sensitivity of the analysis, two bounding cases chosen as 2°C above and below the "mid-range" case (Fig. 11) were also analyzed. The bases on which the "mid-range" release temperatures and the ±2°C band width were chosen are explained in Subsection 3.0(c)(ii).

The results of this study are highly dependent upon the assumption that the temperature of the Waddington Canyon regulated releases would closely follow the average natural water temperatures. In order to ascertain the likely deviation from the natural average temperatures that might occur, a preliminary study[14] was made of the likely inflow and outflow temperatures for Mosley Creek, Nude Canyon and Waddington Canyon. The three projects were treated as a system of reservoirs each with local inflow. As shown on Fig. 11, the resulting alternative schedule of release temperatures from Waddington Canyon is within the limits of the three cases already analyzed. Thus the downstream effects of such release temperatures would be within the limits previously analyzed.

It is again noted that these pre- versus post-project comparisons were made between the computed pre- and post-project cases. This was done in order to remove from this comparison the effect of any anomalies in the input data that produced differences between the computed and observed natural results.

(b) Tailrace at Damsite

Figs. 12 to 18 summarize the temperature results of the "mid-range" post-project runs for 1983. Fig. 12 compares the "mid-range" post-project release temperatures used as the starting temperature for the post-project runs with the natural 1983 temperatures at XH 300. The pre- versus post-project differences from this comparison were small as a result of the initial assumption that,

on average, water at natural temperatures could be released without expensive multiport withdrawal facilities. In order to indicate the sensitivity of the lower Homathko River to the range of Waddington Canyon release temperatures, the results at key locations are presented for the "Plus 2°C" case in Figs. 19 to 24 and for the "Minus 2°C" case in Figs. 25 to 30.

These pre- versus post-project comparisons are intended to determine the differences expected to result from the project and not the exact magnitude of the post-project temperatures. Figs. 12 to 18 show very small pre- versus post-project differences. The computed pre- and post-project temperatures showed a tendency to decrease in the downstream direction. However, the computed natural temperatures had a tendency to underestimate the observed temperatures and to decrease in the downstream direction when the observed temperatures did not. These tendencies were discussed in Subsection 4(b)(i) and (ii). The main conclusion for this case is that the pre- versus post-project differences would be small.

The temperature spike apparent on Figs. 12 to 18 near the first of June was the result of an error in the magnitude of the tributary discharge. By mistake the tributary inflows for 1 day were given a negative sign. The effect was more obvious for the post-project case as Waddington Canyon releases during the late spring would be considerably less than in the natural case. The spike was of short duration and of no consequence to the overall analyses as its effects did not persist beyond 2 or 3 days.

For the mid-range" case the pre- versus post-project differences have been shown to be very small. For the "Plus 2°C" case the pre- versus post-project differences were found to remain approximately constant at +2°C between the tailrace exit and XLH 140 and then to decrease gradually to +0.5°C at XLH 30. For the "Minus 2°C" case the pre- versus post-project differences were found to remain

approximately -2°C between the tailrace exit and the XLH 140 and then gradually decrease to -0.8°C at XLH 30.

(c) 2.7 km Tailrace Tunnel

The 2.7 km tailrace tunnel for the Waddington Canyon Project would exit at cross section XLH 155 which would be upstream of Coola Creek (Fig. 1). Figs. 31 to 35 present the results of the "mid-range" post-project runs for 1983. These results showed that for points downstream of the tailrace exit there would be little change from the results with the tailrace at the damsite. With the tailrace at the damsite the longitudinal temperature gradient along the Homathko due to the combined effect of mixing with large tributary inflows and of surface heat exchange would not be large. Thus when part of the Homathko would be bypassed by the tailrace tunnel, large differences from the non-bypass case would not be expected at points downstream of the tailrace exit as the initial differences across the bypassed reach were small. This would be particularly true when in the bypassed reach temperature increases from surface heat exchange would be held down by significant inflows from cold tributaries and by short travel times resulting from steep gradients.

The area around cross section XLH 170 would be bypassed by the tailrace tunnel and it has been assumed that the temperatures at XLH 170 would be controlled by Klattasine Creek which is the main inflow to this reach. As the distances are short there would be little modification by surface heat exchange. There would, however, be considerable differences between pre- and post-project temperatures in the bypassed reach. Fig. 31 illustrates this with a comparison plot of natural Homathko versus tributary temperatures. Tributary temperatures were used since under regulation all the flow in this reach would come from tributaries. The post-project temperatures in January, February and December were 2 to

3°C higher than what would realistically be expected as discussed at the end of Subsection 3.0(c)(i). The post-project temperatures in this bypassed reach would be as cool or cooler than natural temperatures during these three winter months.

The plotted results for the "Plus 2°C" and "Minus 2°C" have not been presented as they were within 0 to 0.2°C of the corresponding plots for the case of the "Tailrace at Damsite". This similarity is also obvious from the tables of degree-day accumulations discussed under Winter Temperatures in Section 6.0.

(d) 13.2 km Tailrace Tunnel

The 13.2 km tailrace tunnel for the Waddington Canyon Project would exit 2.6 km upstream of cross section XLH 90 which is just upstream of Brew Creek. Figs. 37 and 38 present the results for the "mid-range" case at the cross sections downstream of the tailrace exit. As for the 2.7 km tailrace tunnel there would be little difference at these downstream locations between the results of this case and the case with the tailrace at the damsite. Temperatures at XLH 170 would be identical with those for the 2.7 km tailrace tunnel (Fig. 31). The temperatures at points between XLH 170 and the tailrace exit would be only slightly warmer than at XLH 170 as shown for XLH 120 on Fig. 36 . The January, February and December post-project temperatures at XLH 120 were slightly above what would be realistically expected, as discussed for XLH 170 in the preceeding section on the "2.7 km Tailrace Tunnel". During the summer months the significant inflow from cold tributaries, a steep gradient and short travel time would prevent any significant warming on a daily basis as a result of shallower depths. It is likely that diurnal temperature swings would increase. In the model runs for this study all tributary temperatures were assumed as Brew Creek temperatures. In reality,

tributary temperatures vary, although all are cold, and temperatures in bypassed reaches would reflect this.

As with the 2.7 km tailrace no plotted results are presented for the "Plus 2°C" and "Minus 2°C" cases but the tables of accumulated degree-days have been included.

(e) 1983 - A Typical Year?

The pre- versus post-project comparisons made for this study were based on 1983 data. It is very difficult to know how representative 1983 conditions were of normal conditions. In order to obtain some indication if the observed 1983 water temperatures were above or below normal Fig. 39 was plotted to show 1983 temperatures versus WSC spot water temperatures (1957-79) for "Homathko at the Mouth". The 1983 water temperatures plotted here are from cross section XLH 70 as the record of 1983 water temperatures at the WSC station was collected in a stagnant pool and is not typical of average river conditions as discussed previously. An examination of Figs. 17 and 18 shows that the computed natural water temperatures at XLH 70 were very similar to those at XLH 30 (WSC). However, the data from the three field temperature surveys (Subsection 4.0(b)(i)) showed that there can be a drop in temperature between XLH 70 and "Homathko at the Mouth" as a result of the cold Heakamie and Jewakwa inflows. The magnitude of the drop was found as 0°C, 1.3°C and 0.5°C on 5 July, 18 August and 17 October 1983, respectively. As there was obviously considerable variation and the maximum range was not large, no adjustments were applied to the temperatures at XLH 70 and "the Mouth" for this comparison.

An examination of the diurnal temperature variation at XLH 70 showed that during the summer the daily minimum temperature occurred around 0900 and the daily maximum around 1800 with a diurnal amplitude of 1.5°C. Thus during mid-day when WSC staff

would likely have been at this remote site during a metering trip and collected spot temperatures, the temperature would likely be near the daily average. By comparing the 1983 mean monthly water temperature with the WSC spot temperatures it can be intimated that the water temperatures for various months ranked as follows:

1983

June	about average
July	below average
August	above average
September	below average
October	about average
November	about average
December	below average

On average the months from June to December had a near average temperature but there were significant swings to each side of the average in various months. The above analysis assumes that the WSC spot temperatures were representative of the months in which they were taken. This would be true only in a very general sense. Thus the above indication of the relative position of 1983 is simply that, an indication, and not a verifiable fact.

6.0 WINTER TEMPERATURES

This section presents data on the accumulation of degree-days over winter for use by ESS's environmental consultants. This data is provided in response to Section 4.0(b) Item 4 of the Terms of Reference. The degree-days were accumulated with reference to 0°C. The dates at which specified degree-day accumulations were reached are presented in Tables 4, 5 and 6 for the following Waddington Canyon tailrace locations: "Tailrace at the Damsite", "2.7 km" and "13.2 km Tailrace Tunnels", respectively. The following four cases were considered:

1. Natural Flows and Temperatures.
2. Regulated Flows and Average Temperatures.
3. Regulated Flows and Plus 2°C Temperatures.
4. Regulated Flows and Minus 2°C Temperatures.

As the river reach around XLH 170 is an important spawning and rearing area and is bypassed by the two long tailrace tunnels, a special study of the sensitivity of the degree-day accumulation at XLH 170 to variations in tributary temperatures was made. Table 7 shows the degree-day accumulations for three ranges of tributary temperatures: 1983 measured temperatures for Brew Creek, plus 2°C and minus 2°C.

7.0 SIDE CHANNEL TEMPERATURES

As noted in the Terms of Reference secondary or side channels "often have independent water sources (hillslope flow, groundwater) and appear to be heavily used by spawning and rearing fish". If the side channels have independent water sources they may have warmer winter temperature regimes than the mainstem and thus be preferred by fish. The right side channel between XLH 120 and Whitemantle Creek was used by spawning fish and as shown on Fig. 40 from the "20 Mile" Ryan thermograph had winter water temperatures that were as much as 5°C warmer than the mainstem.

During the winter low flow period these side channels are cut off from the colder mainstem flows. Under post-project conditions winter flows would be much higher and, would probably flow through these side channels in significant quantities assuming no changes in morphology. These discharges would most probably be at temperatures significantly cooler than that normally experienced in the cutoff side channels. The actual effect of these high side channel flows on water temperatures in the gravel layers containing the incubating eggs would be complex. It would depend on the balance achieved between the hydraulic gradient from the stream tending to force water into the streambed and any hydraulic

gradient existing in the surrounding soil that would tend to feed groundwater or interflow into the streambed. The magnitude of the discharges from these groundwater sources would also be important.

Future study of this issue would involve:

1. An inventory of such groundwater discharge areas.

2. An assessment of how important they were to spawning and egg incubation.

3. Collection of stream temperatures in such areas.

4. Collection of water temperature within the gravels of the streambed.

5. Measurement of the hydraulic gradient within the groundwater aquifer and estimation of discharge.

If it were found that changes in the water temperature of side channels would result in serious detrimental effects on the fish habitat, consideration could be given to the construction and maintenance of low weirs and dykes to limit the amount of water entering the upstream end of the more important side channels.

8.0 FUTURE STUDIES

When the Preliminary Environmental Studies for the Homathko Development are resumed, the thermal regime studies should be designed to take account of the points raised in the following discussion:

1. Future thermal regime studies of the lower Homathko River should be designed to provide a minimum of 3 years of field data so that

variable conditions can be sampled and used to provide a preliminary estimate of post-project temperature variability. A minimum of 5 years are necessary before any statistical inference about mean conditions can be drawn. Usually 3 years of field data are collected during the preliminary stages of investigations. If the decision to proceed with more detailed studies of the project is made, additional data can be collected, if necessary, to provide a statistical basis for the conclusion of the preliminary studies.

On the resumption of studies, field data collection should begin 1 year in advance of full scale studies. This way a total of 3 years of data can be available from the current study, the year in advance of future studies, and the year in which full scale studies resumed. Concurrent with the collection of water temperature data, meteorological data must be collected at the Brew Creek station. The required parameters are dry bulb (air) temperature, wet bulb or relative humidity for computing dew point, wind speed and solar radiation.

2. Reservoir water temperature studies should be a priority in future investigations unless none of the pre- versus post-project water temperature differences would result in a potential fisheries problem. If no fisheries problems in the lower Homathko are foreseen, it may still be necessary to conduct a study of reservoir water temperatures for other reasons. In such circumstances the priority attached to the study would be lower. The other reasons could range from a need for more knowledge on the aquatic environment of the reservoir to an improvement in the ease with which the project passes through the regulatory process.

If conducted the reservoir study should be done in two phases: a) preparatory, general investigations and b) mathematical modelling. This study should review the ±2°C band width of release temperatures used in this study.

3. In order to improve the design of the water temperature data collection network, the effects of a range of tributary temperatures should be examined with the existing model. As data collection should start 1 year in advance of detailed office studies, this preliminary examination should be done 2 years in advance of the resumption of studies.

4. In future studies an assessment should be made of the need for the study of water level and discharge variations under rapid load fluctuations that was deleted as a result of budget restraint. The current study concentrated on the provision of a preliminary estimate of the range of water temperature changes between natural and regulated conditions. The present relatively simple representation of the Homathko River gave a good representation of discharges and temperatures along the Homathko for this purpose. Water levels at particular locations are highly dependent on the local river channel geometry. Thus if water level fluctuations at particular locations are to be examined, considerable refinements to the river channel geometry used in the model would be required.

5. In future thermal regime investigations on other rivers, the experience from this study is that limited field and office studies made a year in advance could have considerably reduced the surveying costs in support of the thermal regime study. This holds if the objective is to conduct a thermal regime study. The inclusion of a study of rapid load fluctuations on discharge and depth would considerably increase the amount of surveying required. It should also be noted that other hydrologic and river morphology studies require considerable surveying support. The ability to

test the sensitivity of the model of the river to variations in cross section shape, river slope, tributary temperatures and discharges, and meteorological parameters would also aid considerably in the design of the data collection program.

6. A study of the winter temperatures in the side channels used for spawning should be a priority in future studies as discussed in Section 7.0.

9.0 CONCLUSIONS

This report summarizes the work done on the Preliminary Thermal Regime Study and presents conclusions and recommendations based on data for 1983. As outlined in the Terms of Reference it was intended that this report would provide the basis for further work as part of the preliminary environmental studies. As further studies have been postponed indefinitely the conclusions are made in two parts; conclusions on the nature of the present and future studies and tentative conclusions on the effect of regulation on water temperatures.

With respect to the nature of the studies it is concluded that:

1. the present data base of 1 year is inadequate for studies forming the basis for the Preliminary Environmental Assessment, and

2. a study of side channel temperatures should be a priority in future investigations.

The following tentative conclusions are drawn on the effect of regulation on water temperatures:

1. Under regulated conditions with the assumed Waddington Canyon release temperatures, there would be only minor temperature differences from the natural condition at points downstream of each of the three alternative tailrace locations.

2. Under regulated conditions the river temperatures in the river reaches bypassed by the tailrace tunnel would be 3° to 4° colder in mid-summer than under natural conditions.

3. The regulated temperatures would not differ greatly from those calculated if the Waddington Canyon release temperatures varied ±2°C.

4. Estimated Waddington Canyon release temperatures are approximate only. The ±2°C range in release temperatures adopted for this study is adequate to provide for reasonable variability in release temperatures.

10.0 RECOMMENDATIONS

As a result of this examination of the thermal regime of the lower Homathko River the following recommendations are made:

1. A more accurate assessment of release temperatures from Waddington Canyon Reservoir will be required in future investigations unless the pre- versus post-project water temperature differences estimated herein would not result in a potential fisheries problem.

2. The interaction of surface streamflows and groundwater in side channels used for spawning and rearing should be examined as a priority item in future studies.

3. The collection of water temperature data and associated meteorological and solar radiation data should be begun 1 year in advance of the resumption of full scale studies.

4. Model studies to examine the effects of a range of tributary temperatures should be undertaken to aid in the design of an

efficient data collection network. These should be undertaken 2 years in advance of the resumption of full-scale studies.

5. The need for a detailed reservoir water temperature study temperature at the Waddington Canyon Project for reasons other than the provision of release temperatures should be assessed during the next phase of study.

6. The need for the study of water level and discharge variations during rapid load fluctuations should be assessed during future studies.

7. In future thermal regime investigations in other river basins, limited field and office studies should be made 1 year in advance of the initiation of the full-scale studies to assist in the design of efficient and cost effective data collection and surveying programs.

PRELIMINARY

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11. Technology Resource Inc., Stikine-Iskut Hydroelectric Development Simulation of Selective Withdrawal and its Effect on Release Temperatures, November 1983.

12. Raphael, J.M, "Prediction of Temperature in Rivers and Reservoirs", Journal of the Power Division, ASCE, July 1962, pp. 154-181.

13. Thackston, E.L. and F.L. Parker, Effect of Geographical Location on Cooling Pond Requirements and Performance, Environmental Protection Agency Project 16130 FDQ, Vanderbitt University, Nashville, Tennessee, March 1971.

14. Cass, D.E. B.C. Hydro memo to Lum, D.Y., "Waddington Release Temperatures", 27 March 1984.

GLOSSARY

1. **Invert:** The lowest visible surface, the bottom of a channel.

2. **Shading Diagram:** The plot of the horizon line in degrees of altitude as observed by turning in a full circle about a given point. The plot is made on a circular chart on which concentric circles represent degrees of altitude.

3. **Channel Conveyance:** A measure of the carrying capacity of a channel section when the water is at a particular elevation. The discharge a channel can carry with that water level is the conveyance times the square root of the slope.

PRELIMINARY

TABLE 1

NATURAL AND REGULATED DISCHARGES
WADDINGTON CANYON PROJECT - 1983

Months	Natural (m^3/s)	Regulated (m^3/s)
January	27.0	121
February	27.3	115
March	28.2	121
April	40.5	107
May	168	145
June	298	165
July	279	135
August	292	152
September	132	112
October	50.9	100
November	41.0	119
December	21.2	116
Average	117.1	125.7*1

*1 The estimated average regulated discharge agrees only approximately with the observed natural discharge as it was prepared before year-end from estimates of natural flows.

TABLE 2

PROFILES OF DAILY MEAN WATER TEMPERATURES
LOWER HOMATHKO - 1983

Date	XH 300	XLH 170	XLH 140	XLH 70
May 1			6.0	
10			6.1	
20	7.2		8.8	
30	6.9		7.6	
Jun 10	5.6		6.4	6.0
20	6.1		7.6	7.6
30	7.7		7.7	7.9
Jul 10	7.6		7.6	7.5
20	8.3		9.0	7.6
30	8.5		9.6	8.1
Aug 10	8.5		8.2	-
20	6.8		7.5	7.8
30	7.1		7.9	7.9
Sep 10	6.4	6.2	7.2	7.2
20	6.5	6.0	6.7	7.3
30	4.4	5.3	4.9	6.0
Oct 10	4.1	4.3	4.9	-
20	5.7	5.0		6.0
30	4.9	3.6		4.6

TABLE 3

SUMMARY OF FIELD WATER TEMPERATURE PROFILES
(PROFILE OF 5 JULY 1983)
LOWER HOMATHKO RIVER - 1983

Time PDT	Station or Tributary	Water Temperature °C		Time Adjusted Temperature °C		
		Homathko River	Tributary	10:00	14:00	16:00
07:45	XLH 140	7.1				
	Coola Creek		2.9			
	Jones Creek		6.0			
09:55	XLH 170	7.0		7.0	7.4	8.2
10:25	XLH 140	7.1				
	Scar Creek		6.5			
12:10	1/4 mi. U/S of Whitemantle	8.0				
	Whitemantle Creek		6.6			
13:20	XLH 90	8.5				
	Brew Creek		7.2			
14:15	XLH 70	9.0		7.7	9.0	9.3
	Jewakwa River		5.3			
	Heakamie River		5.0			
15:50	XLH 30	9.0		7.4	8.7	9.0
10.00	XLH 20	9.0				
16:10	XLH 10	9.2				
16.20	Estuary Potatoe Point	8.6				

Daily Mean Discharge: Homathko River at Tragedy Canyon - 253 m^3/s
Daily Mean Discharge: Homathko River at the Mouth - 479 m^3/s
Percent Increase in Discharge = 89 percent

TABLE 3 - (Cont'd)

SUMMARY OF FIELD WATER TEMPERATURE PROFILES
(PROFILE OF 18, 19 AUGUST 1983)
LOWER HOMATHKO RIVER - 1983

Time PDT	Station or Tributary	Water Temperature °C: Homathko River	Water Temperature °C: Tributary	Time Adjusted Temperature °C: 07:30	10:30/ 11:30	15:00
		18 August 1983				
10:45	Estuary - Potatoe Point	6.4				
11.06	XLH 10	6.4				
11:11	XLH 20	6.3				
11:20	WSC Intake	6.3				
11:25	XLH 30	6.4		6.4	/6.4	7.3
14:15	Heakamie River		4.6			
14:30	Jewakwa River		4.6			
14:55	XLH 70	8.6		7.7	/7.7	8.6
		19 August 1983				
06:33	XLH 140	6.8				
06:55	Coola Creek		2.2			
07:22	Jones Creek		5.9			
07:26	XLH 170	6.9		6.9	7.2/	8.4
08:42	XLH 140	6.8				
08:49	Scar Creek		5.1			
09:22	W/S of Whitemantle Creek	6.9				
	Whitemantle Creek		4.6			
09:52	XLH 90	7.0				
10:10	Brew Creek		4.4			
10:28	XLH 70	7.2		7.2	7.2/	8.6

18 August 1983:

Daily Mean Discharge: Homathko River at Tragedy Canyon - 273 m^3/s
Daily Mean Discharge: Homathko River at the Mouth - 548 m^3/s
Percent Increase in Discharge = 101 percent

TABLE 3 - (Cont'd)

SUMMARY OF FIELD WATER TEMPERATURE PROFILES
(PROFILE OF 17 OCTOBER 1983)
LOWER HOMATHKO RIVER - 1983

Time PDT	Station or Tributary	Water Temperature °C	
		Homathko River	Tributary
14:30	XLH 140	6.0	
15:40	WSC Tragedy	5.7	
15:55	XH 300	5.8	
	Klattasine Creek		5.6
16:00	XLH 170	6.0	
16:15	Jones Creek		5.8
16:35	Coola Creek		4.1
16:40	XLH 140	6.3	
16:55	Scar Creek		5.5
17:20	Whitemantle Creek		4.8
17:30	XLH 90	6.5	
17:30	Brew Creek		5.4
17:40	XLH 70	6.7	
17:50	Jewakwa River		3.6
17:48	Heakamie River		3.0
18:20	XLH 30	6.2	

Daily Mean Discharge: Homathko River at Tragedy Canyon - 36.5 m^3/s
Daily Mean Discharge: Homathko River at the Mouth - 79.1 m^3/s
Percent Increase in Discharge = 117 percent

Discharge for Homathko River at Tragedy Canyon at 15:40 - 52 m^3/s
Discharge for Homathko River at the Mouth at 18:20 - 67.5 m^3/s
Increase in Discharge at time of survey = 30 percent

TABLE 4

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 1 August)
TAILRACE AT DAMSITE

Location	Accumulated Degree Day				
	417	611	806	889	972 (Celsius)
	750	1100	1450	1600	1750 (Fahrenheit)
XLH 170					
Natural	29 Sep.	9 Nov.	31 Jan.	9 Mar.	31 Mar.
Regulated with Average Temperatures	25 Sep.	30 Oct.	13 Jan.	14 Feb.	9 Mar.
Regulated with Plus 2°C Temperatures	13 Sep.	6 Oct.	3 Nov.	18 Nov.	6 Dec.
Regulated with Minus 2°C Temperatures	22 Oct.	4 Apr.	25 May	11 Jun.	26 Jun.
XLH 120					
Natural	4 Oct.	19 Nov.	27 Feb.	26 Mar.	14 Apr.
Regulated with Average Temperatures	2 Oct.	12 Nov.	6 Feb.	3 Mar.	24 Mar.
Regulated with Plus 2°C Temperatures	20 Sep.	17 Oct.	20 Nov.	10 Dec.	2 Jan.
Regulated with Minus 2°C Temperatures	27 Oct.	4 Apr.	25 May	10 Jun.	26 Jun.
XLH 30					
Natural	15 Oct.	11 Dec.	14 Mar.	7 Apr.	25 Apr.
Regulated with Average Temperatures	13 Oct.	8 Dec.	3 Mar.	25 Mar.	13 Apr.
Regulated with Plus 2°C Temperatures	3 Oct.	6 Nov.	29 Dec.	23 Jun.	14 Feb.
Regulated with Minus 2°C Temperatures	30 Oct.	25 Mar.	18 May	4 Jun.	20 Jun.

TABLE 4 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 15 August)
TAILRACE AT DAMSITE

Location	Accumulated Degree Day				
	417	611	806	889	972 (Celsius)
	750	1100	1450	1600	1750 (Fahrenheit)
XLH 170					
Natural	24 Oct.	22 Dec.	20 Mar.	7 Apr.	22 Apr.
Regulated with Average Temperatures	14 Oct.	3 Dec.	23 Feb.	16 Mar.	3 Apr.
Regulated with Plus 2°C Temperatures	29 Sep.	25 Oct.	29 Nov.	20 Dec.	10 Jan.
Regulated with Minus 2°C Temperatures	9 Feb.	30 Apr.	11 Jun.	26 Jun.	10 Jul.
XLH 120					
Natural	30 Oct.	15 Jan.	2 Apr.	19 Apr.	4 May
Regulated with Average Temperatures	21 Oct.	25 Dec.	8 Mar.	28 Mar.	15 Apr.
Regulated with Plus 2°C Temperatures	6 Oct.	5 Nov.	19 Dec.	11 Jan.	1 Feb.
Regulated with Minus 2°C Temperatures	8 Feb.	28 Apr.	10 Jun.	26 Jun.	10 Jul.
XLH 30					
Natural	8 Nov.	8 Feb.	11 Apr.	29 Apr.	14 May
Regulated with Average Temperatures	2 Nov.	25 Jan.	27 Mar.	15 Apr.	1 May
Regulated with Plus 2°C Temperatures	19 Oct.	29 Nov.	27 Jan.	17 Feb.	6 Mar.
Regulated with Minus 2°C Temperatures	15 Jan.	20 Apr.	3 Jun.	19 Jun.	5 Jul.

TABLE 4 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 29 August)
TAILRACE AT DAMSITE

Location	Accumulated Degree Day 417 / 750	611 / 1100	806 / 1450	889 / 1600	972 (Celsius) / 1750 (Fahrenheit)
XLH 170					
Natural	15 Nov.	17 Feb.	10 Apr.	25 Apr.	8 May
Regulated with Average Temperatures	6 Nov.	25 Jan.	22 Mar.	9 Apr.	25 Apr.
Regulated with Plus 2°C Temperatures	17 Oct.	17 Nov.	2 Jan.	23 Jan.	10 Feb.
Regulated with Minus 2°C Temperatures	27 Mar.	20 May	26 Jun.	10 Jul.	23 Jul.
XLH 120					
Natural	23 Nov.	2 Mar.	21 Apr.	5 May	19 May
Regulated with Average Temperatures	13 Nov.	8 Feb.	31 Mar.	17 Apr.	3 May
Regulated with Plus 2°C Temperatures	23 Oct.	29 Nov.	20 Jan.	8 Feb.	26 Feb.
Regulated with Minus 2°C Temperatures	23 Mar.	18 May	25 Jun.	10 Jul.	25 Jul.
XLH 30					
Natural	7 Dec.	11 Mar.	29 Apr.	14 May	29 May
Regulated with Average Temperatures	27 Nov.	26 Feb.	15 Apr.	2 May	18 May
Regulated with Plus 2°C Temperatures	6 Nov.	28 Dec.	20 Feb.	9 Mar.	25 Mar.
Regulated with Minus 2°C Temperatures	10 Mar.	9 May	18 Jun.	4 Jul.	20 Jul.

TABLE 4 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 12 September)
TAILRACE AT DAMSITE

Location	Accumulated Degree Day				
	417	611	806	889	972 (Celsius)
	750	1100	1450	1600	1750 (Fahrenheit)
XLH 170					
Natural	21 Dec.	19 Mar.	26 Apr.	9 May	21 May
Regulated with Average Temperatures	12 Dec.	28 Feb.	13 Apr.	28 Apr.	12 May
Regulated with Plus 2°C Temperatures	5 Nov.	16 Dec.	2 Feb.	19 Feb.	5 Mar.
Regulated with Minus 2°C Temperatures	21 Apr.	5 Jun.	9 Jul.	22 Jul.	-
XLH 120					
Natural	6 Jan.	29 Mar.	6 May	19 May	1 Jun.
Regulated with Average Temperatures	23 Dec.	7 Mar.	19 Apr.	5 May	19 May
Regulated with Plus 2°C Temperatures	12 Nov.	29 Dec.	15 Feb.	2 Mar.	17 Mar.
Regulated with Minus 2°C Temperatures	17 Apr.	2 Jun.	8 Jul.	23 Jul.	-
XLH 30					
Natural	20 Jan.	3 Apr.	14 May	28 May	11 Jun.
Regulated with Average Temperatures	11 Jan.	19 Mar.	1 May	17 May	31 May
Regulated with Plus 2°C Temperatures	26 Nov.	24 Jan.	10 Mar.	26 Mar.	10 Apr.
Regulated with Minus 2°C Temperatures	5 Apr.	24 May	1 Jul.	18 Jul.	-

TABLE 4 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 26 September)
TAILRACE AT DAMSITE

Location	Accumulated Degree Day					
	417	611	806	889	972	(Celsius)
	750	1100	1450	1600	1750	(Fahrenheit)
XLH 170						
Natural	13 Feb.	8 Apr.	10 May	22 May	4 Jun.	
Regulated with Average Temperatures	26 Jan.	23 Mar.	30 Apr.	14 May	27 May	
Regulated with Plus 2°C Temperatures	28 Nov.	16 Jan.	26 Feb.	11 Mar.	25 Mar.	
Regulated with Minus 2°C Temperatures	8 May	17 Jun.	20 Jul.	-	-	
XLH 120						
Natural	23 Feb.	17 Apr.	20 May	2 Jun.	15 Jun.	
Regulated with Average Temperatures	2 Feb.	28 Mar.	5 May	20 May	2 Jun.	
Regulated with Plus 2°C Temperatures	5 Dec.	26 Jan.	7 Mar.	21 Mar.	3 Apr.	
Regulated with Minus 2°C Temperatures	5 May	15 Jun.	20 Jul.	-	-	
XLH 30						
Natural	25 Feb.	21 Apr.	27 May	9 Jun.	24 Jun.	
Regulated with Average Temperatures	14 Feb.	7 Apr.	16 May	30 May	13 Jun.	
Regulated with Plus 2°C Temperatures	23 Dec.	16 Feb.	27 Mar.	11 Apr.	24 Apr.	
Regulated with Minus 2°C Temperatures	24 Apr.	6 Jun.	14 Jul.	30 Jul.	-	

TABLE 4 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 10 October)
TAILRACE AT DAMSITE

Location	Accumulated Degree Day 417 750	611 1100	806 1450	889 1600	972 1750 (Celsius) (Fahrenheit)
XLH 170					
Natural	7 Mar.	20 Apr.	20 May	2 Jun.	15 Jun.
Regulated with Average Temperatures	24 Feb.	10 Apr.	14 May	27 May	8 Jun.
Regulated with Plus 2°C Temperatures	26 Dec.	10 Feb.	16 Mar.	29 Mar.	10 Apr.
Regulated with Minus 2°C Temperatures	22 May	28 Jun.	29 Jul.	-	-
XLH 120					
Natural	16 Mar.	28 Apr.	29 May	12 Jun.	25 Jun.
Regulated with Average Temperatures	28 Feb.	14 Apr.	19 May	1 Jun.	14 Jun.
Regulated with Plus 2°C Temperatures	3 Jan.	18 Feb.	24 Mar.	6 Apr.	19 Apr.
Regulated with Minus 2°C Temperatures	18 May	25 Jun.	31 Jul.	-	-
XLH 30					
Natural	16 Mar.	2 May	5 Jun.	20 Jun.	3 Jul.
Regulated with Average Temperatures	6 Mar.	21 Apr.	28 May	11 Jun.	25 Jun.
Regulated with Plus 2°C Temperatures	18 Jan.	6 Mar.	11 Apr.	25 Apr.	8 May
Regulated with Minus 2°C Temperatures	7 May	17 Jun.	24 Jul.	-	-

TABLE 4 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 24 October)
TAILRACE AT DAMSITE

Location	Accumulated Degree Day				
	417	611	806	889	972 (Celsius)
	750	1100	1450	1600	1750 (Fahrenheit)
XLH 170					
Natural	27 Mar.	1 May	30 May	13 Jun.	25 Jun.
Regulated with Average Temperatures	15 Mar.	24 Apr.	26 May	7 Jun.	18 Jun.
Regulated with Plus 2°C Temperatures	21 Jan.	1 Mar.	1 Apr.	13 Apr.	24 Apr.
Regulated with Minus 2°C Temperatures	1 Jun.	6 Jul.	-	-	-
XLH 120					
Natural	2 Apr.	9 May	9 Jun.	22 Jun.	4 Jul.
Regulated with Average Temperatures	18 Mar.	28 Apr.	30 May	12 Jun.	24 Jun.
Regulated with Plus 2°C Temperatures	27 Jan.	6 Mar.	8 Apr.	21 Apr.	2 May
Regulated with Minus 2°C Temperatures	28 May	4 Jul.	-	-	-
XLH 30					
Natural	3 Apr.	13 May	15 Jun.	29 Jun.	13 Jul.
Regulated with Average Temperatures	24 Mar.	5 May	8 Jun.	22 Jun.	6 Jul.
Regulated with Plus 2°C Temperatures	10 Feb.	22 Mar.	25 Apr.	9 May	22 May
Regulated with Minus 2°C Temperatures	19 May	26 Jun.	-	-	-

TABLE 4 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 7 November)
TAILRACE AT DAMSITE

Location	Accumulated Degree Day					
	417	611	806	889	972	(Celsius)
	750	1100	1450	1600	1750	(Fahrenheit)
XLH 170						
Natural	9 Apr.	11 May	9 Jun.	23 Jun.	4 Jul.	
Regulated with Average Temperatures	29 Mar.	5 May	4 Jun.	16 Jun.	26 Jun.	
Regulated with Plus 2°C Temperatures	10 Feb.	16 Mar.	14 Apr.	25 Apr.	6 May	
Regulated with Minus 2°C Temperatures	8 Jun.	11 Jul.	-	-	-	
XLH 120						
Natural	15 Apr.	18 May	19 Jun.	1 Jul.	13 Jul.	
Regulated with Average Temperatures	1 Apr.	8 May	9 Jun.	21 Jun.	2 Jul.	
Regulated with Plus 2°C Temperatures	15 Feb.	22 Mar.	20 Apr.	2 May	14 May	
Regulated with Minus 2°C Temperatures	5 Jun.	11 Jul.	-	-	-	
XLH 30						
Natural	16 Apr.	23 May	25 Jun.	8 Jul.	22 Jul.	
Regulated with Average Temperatures	6 Apr.	16 May	18 Jun.	1 Jul.	16 Jul.	
Regulated with Plus 2°C Temperatures	26 Feb.	4 Apr.	7 May	20 May	31 May	
Regulated with Minus 2°C Temperatures	28 May	4 Jul.	-	-	-	

TABLE 4 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 21 November)
TAILRACE AT DAMSITE

Location	Accumulated Degree Day 417 / 750	611 / 1100	806 / 1450	889 / 1600	972 / 1750 (Celsius / Fahrenheit)
XLH 170					
Natural	19 Apr.	19 May	19 Jun.	30 Jun.	11 Jul.
Regulated with Average Temperatures	8 Apr.	13 May	11 Jun.	22 Jun.	3 Jul.
Regulated with Plus 2°C Temperatures	24 Feb.	28 Mar.	24 Apr.	5 May	16 May
Regulated with Minus 2°C Temperatures	12 Jun.	15 Jul.	-	-	-
XLH 120					
Natural	25 Apr.	27 May	27 Jun.	8 Jul.	20 Jul.
Regulated with Average Temperatures	11 Apr.	17 May	16 Jun.	28 Jun.	10 Jul.
Regulated with Plus 2°C Temperatures	29 Feb.	2 Apr.	1 May	12 May	23 May
Regulated with Minus 2°C Temperatures	10 Jun.	15 Jul.	-	-	-
XLH 30					
Natural	27 Apr.	31 May	3 Jul.	17 Jul.	29 Jul.
Regulated with Average Temperatures	17 Apr.	29 May	25 Jun.	10 Jul.	24 Jul.
Regulated with Plus 2°C Temperatures	11 Mar.	15 Apr.	17 May	29 May	10 Jun.
Regulated with Minus 2°C Temperatures	3 Jun.	11 Jul.	-	-	-

TABLE 4 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 5 December)
TAILRACE AT DAMSITE

Location	Accumulated Degree Day				
	417	611	806	889	972 (Celsius)
	750	1100	1450	1600	1750 (Fahrenheit)
XLH 170					
Natural	25 Apr.	24 May	24 Jun.	5 Jul.	16 Jul.
Regulated with Average Temperatures	15 Apr.	18 May	16 Jun.	27 Jun.	7 Jul.
Regulated with Plus 2°C Temperatures	6 Mar.	6 Apr.	3 May	13 May	23 May
Regulated with Minus 2°C Temperatures	13 Jun.	16 Jul.	-	-	-
XLH 120					
Natural	30 Apr.	31 May	1 Jul.	13 Jul.	24 Jul.
Regulated with Average Temperatures	18 Apr.	22 May	21 Jun.	3 Jul.	15 Jul.
Regulated with Plus 2°C Temperatures	11 Mar.	11 Apr.	9 May	20 May	31 May
Regulated with Minus 2°C Temperatures	12 Jun.	17 Jul.	-	-	-
XLH 30					
Natural	3 May	6 Jun.	8 Jul.	22 Jul.	-
Regulated with Average Temperatures	24 Apr.	30 May	1 Jul.	16 Jul.	30 Jul.
Regulated with Plus 2°C Temperatures	21 Mar.	24 Apr.	25 May	5 Jun.	18 Jun.
Regulated with Minus 2°C Temperatures	6 Jun.	14 Jul.	-	-	-

TABLE 5

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 1 August)
2.7 km TAILRACE TUNNEL

Location	Accumulated Degree Day				
	417	611	806	889	972 (Celsius)
	750	1100	1450	1600	1750 (Fahrenheit)
XLH 170					
Natural	29 Sep.	9 Nov.	31 Jan.	9 Mar.	31 Mar.
Reach bypassed by Tailrace Tunnel	4 Nov.	25 Dec.	24 Feb.	20 Mar.	10 Apr.
XLH 120					
Natural	4 Oct.	19 Nov.	27 Feb.	26 Mar.	14 Apr.
Regulated with Average Temperatures	2 Oct.	12 Nov.	3 Feb.	29 Feb.	22 Mar.
Regulated with Plus 2°C Temperatures	20 Sep.	17 Oct.	20 Nov.	9 Dec.	1 Jan.
Regulated with Minus 2°C Temperatures	26 Oct.	31 Mar.	22 May	8 Jun.	24 Jun.
XLH 30					
Natural	15 Oct.	11 Dec.	14 Mar.	7 Apr.	25 Apr.
Regulated with Average Temperatures	12 Oct.	3 Dec.	26 Feb.	20 Mar.	9 Apr.
Regulated with Plus 2°C Temperatures	3 Oct.	5 Nov.	25 Dec.	19 Jan.	9 Feb.
Regulated with Minus 2°C Temperatures	29 Oct.	18 Mar.	13 May	30 May	16 Jun.

TABLE 5 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 15 August)
2.7 km TAILRACE TUNNEL

Location	Accumulated Degree Day 417 / 750	611 / 1100	806 / 1450	889 / 1600	972 (Celsius) / 1750 (Fahrenheit)
XLH 170					
Natural	24 Oct.	22 Dec.	20 Mar.	7 Apr.	22 Apr.
Reach bypassed by Tailrace Tunnel	23 Nov.	16 Jan.	17 Mar.	7 Apr.	28 Apr.
XLH 120					
Natural	30 Oct.	15 Jan.	2 Apr.	19 Apr.	4 May
Regulated with Average Temperatures	21 Oct.	22 Dec.	5 Mar.	25 Mar.	12 Apr.
Regulated with Plus 2°C Temperatures	6 Oct.	5 Nov.	18 Dec.	9 Jan.	30 Jan.
Regulated with Minus 2°C Temperatures	29 Jan.	25 Apr.	8 Jun.	23 Jun.	8 Jul.
XLH 30					
Natural	8 Nov.	8 Feb.	11 Apr.	29 Apr.	14 May
Regulated with Average Temperatures	31 Oct.	18 Jan.	22 Mar.	10 Apr.	27 Apr.
Regulated with Plus 2°C Temperatures	18 Oct.	27 Nov.	23 Jan.	13 Feb.	2 Mar.
Regulated with Minus 2°C Temperatures	28 Dec.	14 Apr.	30 May	15 Jun.	1 Jul.

TABLE 5 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 29 August)
2.7 km TAILRACE TUNNEL

Location	Accumulated Degree Day 417 / 750	611 / 1100	806 / 1450	889 / 1600	972 (Celsius) / 1750 (Fahrenheit)
XLH 170					
Natural	15 Nov.	17 Feb.	10 Apr.	25 Apr.	8 May
Reach bypassed by Tailrace Tunnel	11 Dec.	8 Feb.	3 Apr.	24 Apr.	13 May
XLH 120					
Natural	23 Nov.	2 Mar.	21 Apr.	5 May	19 May
Regulated with Average Temperatures	13 Nov.	4 Feb.	29 Mar.	15 Apr.	1 May
Regulated with Plus 2°C Temperatures	23 Oct.	28 Nov.	18 Jan.	6 Feb.	23 Feb.
Regulated with Minus 2°C Temperatures	19 Mar.	15 May	23 Jun.	8 Jul.	23 Jul.
XLH 30					
Natural	7 Dec.	11 Mar.	29 Apr.	14 May	29 May
Regulated with Average Temperatures	25 Nov.	21 Feb.	11 Apr.	28 Apr.	14 May
Regulated with Plus 2°C Temperatures	5 Nov.	25 Dec.	16 Feb.	5 Mar.	21 Mar.
Regulated with Minus 2°C Temperatures	2 Mar.	4 May	14 Jun.	30 Jun.	16 Jul.

PRELIMINARY

TABLE 5 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 12 September)
2.7 km TAILRACE TUNNEL

Location	Accumulated Degree Day				
	417	611	806	889	972 (Celsius)
	750	1100	1450	1600	1750 (Fahrenheit)
XLH 170					
Natural	21 Dec.	19 Mar.	26 Apr.	9 May	21 May
Reach bypassed by Tailrace Tunnel	27 Dec.	27 Feb.	19 Apr.	9 May	27 May
XLH 120					
Natural	6 Jan.	29 Mar.	6 May	19 May	1 Jun.
Regulated with Average Temperatures	20 Dec.	4 Mar.	17 Apr.	2 May	17 May
Regulated with Plus 2°C Temperatures	11 Nov.	27 Dec.	12 Feb.	29 Feb.	15 Mar.
Regulated with Minus 2°C Temperatures	14 Apr.	30 May	6 Jul.	21 Jul.	-
XLH 30					
Natural	20 Jan.	3 Apr.	14 May	28 May	11 Jun.
Regulated with Average Temperatures	6 Jan.	15 Mar.	27 Apr.	13 May	28 May
Regulated with Plus 2°C Temperatures	25 Nov.	20 Jan.	6 Mar.	23 Mar.	6 Apr.
Regulated with Minus 2°C Temperatures	30 Mar.	20 May	27 Jun.	14 Jul.	29 Jul.

TABLE 5 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 26 September)
2.7 km TAILRACE TUNNEL

Location	Accumulated Degree Day 417 / 750	611 / 1100	806 / 1450	889 / 1600	972 / 1750 (Celsius / Fahrenheit)
XLH 170					
Natural	13 Feb.	8 Apr.	10 May	22 May	4 Jun.
Reach bypassed by Tailrace Tunnel	15 Jan.	15 Mar.	3 May	22 May	10 Jun.
XLH 120					
Natural	23 Feb.	17 Apr.	20 May	2 Jun.	15 Jun.
Regulated with Average Temperatures	30 Jan.	25 Mar.	3 May	17 May	31 May
Regulated with Plus 2°C Temperatures	5 Dec.	24 Jan.	5 Mar.	19 Mar.	1 Apr.
Regulated with Minus 2°C Temperatures	2 May	13 Jun.	18 Jul.	-	-
XLH 30					
Natural	25 Feb.	21 Apr.	27 May	9 Jun.	24 Jun.
Regulated with Average Temperatures	9 Feb.	3 Apr.	12 May	27 May	11 Jun.
Regulated with Plus 2°C Temperatures	20 Dec.	13 Feb.	24 Mar.	7 Apr.	21 Apr.
Regulated with Minus 2°C Temperatures	19 Apr.	2 Jun.	10 Jul.	26 Jul.	-

PRELIMINARY

TABLE 5 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 10 October)
2.7 km TAILRACE TUNNEL

Location	Accumulated Degree Day				
	417	611	806	889	972 (Celsius)
	750	1100	1450	1600	1750 (Fahrenheit)
XLH 170					
Natural	7 Mar.	20 Apr.	20 May	2 Jun.	15 Jun.
Reach bypassed by Tailrace Tunnel	31 Jan.	29 Mar.	15 May	2 Jun.	20 Jun.
XLH 120					
Natural	16 Mar.	28 Apr.	29 May	12 Jun.	25 Jun.
Regulated with Average Temperatures	26 Feb.	12 Apr.	17 May	30 May	12 Jun.
Regulated with Plus 2°C Temperatures	1 Jan.	16 Feb.	22 Mar.	4 Apr.	17 Apr.
Regulated with Minus 2°C Temperatures	15 May	23 Jun.	28 Jul.	-	-
XLH 30					
Natural	16 Mar.	2 May	5 Jun.	20 Jun.	3 Jul.
Regulated with Average Temperatures	2 Mar.	18 Apr.	25 May	8 Jun.	22 Jun.
Regulated with Plus 2°C Temperatures	15 Jun.	3 Mar.	8 Apr.	21 Apr.	5 May
Regulated with Minus 2°C Temperatures	3 May	14 Jun.	21 Jul.	-	-

TABLE 5 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 24 October)
2.7 km TAILRACE TUNNEL

Location	Accumulated Degree Day 417 / 750	611 / 1100	806 / 1450	889 / 1600	972 / 1750 (Celsius / Fahrenheit)
XLH 170					
Natural	27 Mar.	1 May	30 May	13 Jun.	25 Jun.
Reach bypassed by Tailrace Tunnel	20 Feb.	13 Apr.	28 May	16 Jun.	3 Jul.
XLH 120					
Natural	2 Apr.	9 May	9 Jun.	25 Jun.	4 Jul.
Regulated with Average Temperatures	16 Mar.	26 Apr.	29 May	11 Jun.	23 Jun.
Regulated with Plus 2°C Temperatures	26 Jan.	6 Mar.	7 Apr.	19 Apr.	1 May
Regulated with Minus 2°C Temperatures	26 May	2 Jul.	-	-	-
XLH 30					
Natural	3 Apr.	13 May	15 Jun.	29 Jun.	13 Jul.
Regulated with Average Temperatures	20 Mar.	1 May	6 Jun.	20 Jun.	4 Jul.
Regulated with Plus 2°C Temperatures	7 Feb.	20 Mar.	22 Apr.	5 May	19 May
Regulated with Minus 2°C Temperatures	15 May	23 Jun.	30 Jul.	-	-

PRELIMINARY

TABLE 5 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 7 November)
2.7 km TAILRACE TUNNEL

Location	Accumulated Degree Day				
	417	611	806	889	972 (Celsius)
	750	1100	1450	1600	1750 (Fahrenheit)
XLH 170					
Natural	9 Apr.	11 May	9 Jun.	23 Jun.	4 Jul.
Reach bypassed by Tailrace Tunnel	7 Mar.	26 Apr.	9 Jun.	27 Jun.	16 Jul.
XLH 120					
Natural	15 Apr.	18 May	19 Jun.	1 Jul.	13 Jul.
Regulated with Average Temperatures	30 Mar.	6 May	7 Jun.	20 Jun.	2 Jul.
Regulated with Plus 2°C Temperatures	13 Feb.	20 Mar.	19 Apr.	1 May	12 May
Regulated with Minus 2°C Temperatures	3 Jun.	9 Jul.	-	-	-
XLH 30					
Natural	16 Apr.	23 May	25 Jun.	8 Jul.	22 Jul.
Regulated with Average Temperatures	3 Apr.	13 May	16 Jun.	29 Jun.	14 Jul.
Regulated with Plus 2°C Temperatures	24 Feb.	1 Apr.	4 May	17 May	30 May
Regulated with Minus 2°C Temperatures	24 May	1 Jul.	-	-	-

PRELIMINARY

TABLE 5 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 21 November)
2.7 km TAILRACE TUNNEL

Location	Accumulated Degree Day					
	417	611	806	889	972	(Celsius)
	750	1100	1450	1600	1750	(Fahrenheit)
XLH 170						
Natural	19 Apr.	19 May	19 Jun.	30 Jun.	11 Jul.	
Reach bypassed by Tailrace Tunnel	22 Mar.	9 May	20 Jun.	9 Jul.	28 Jul.	
XLH 120						
Natural	25 Apr.	27 May	27 Jun.	8 Jul.	20 Jul.	
Regulated with Average Temperatures	9 Apr.	15 May	15 Jun.	27 Jun.	9 Jul.	
Regulated with Plus 2°C Temperatures	27 Feb.	1 Apr.	29 Apr.	11 May	22 May	
Regulated with Minus 2°C Temperatures	8 Jun.	14 Jul.	-	-	-	
XLH 30						
Natural	27 Apr.	31 May	3 Jul.	17 Jul.	29 Jul.	
Regulated with Average Temperatures	14 Apr.	21 May	24 Jun.	8 Jul.	22 Jul.	
Regulated with Plus 2°C Temperatures	8 Mar.	13 Apr.	14 May	27 May	9 Jun.	
Regulated with Minus 2°C Temperatures	31 May	8 Jul.	-	-	-	

PRELIMINARY

TABLE 5 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 5 December)
2.7 km TAILRACE TUNNEL

Location	Accumulated Degree Day 417 / 750	611 / 1100	806 / 1450	889 / 1600	972 / 1750 (Celsius / Fahrenheit)
XLH 170					
Natural	25 Apr.	24 May	24 Jun.	5 Jul.	16 Jul.
Reach bypassed by Tailrace Tunnel	4 Apr.	20 May	1 Jul.	20 Jul.	-
XLH 120					
Natural	30 Apr.	31 May	1 Jul.	13 Jul.	24 Jul.
Regulated with Average Temperatures	16 Apr.	21 May	20 Jun.	2 Jul.	14 Jul.
Regulated with Plus 2°C Temperatures	10 Mar.	10 Apr.	8 May	19 May	30 May
Regulated with Minus 2°C Temperatures	10 Jun.	15 Jul.	-	-	-
XLH 30					
Natural	3 May	6 Jun.	8 Jul.	22 Jul.	-
Regulated with Average Temperatures	21 Apr.	27 May	29 Jun.	14 Jul.	28 Jul.
Regulated with Plus 2°C Temperatures	19 Mar.	21 Apr.	23 May	4 Jun.	17 Jun.
Regulated with Minus 2°C Temperatures	3 Jun.	11 Jul.	-	-	-

TABLE 6

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 1 August)
13.2 km TAILRACE TUNNEL

Location	Accumulated Degree Day 417 / 750	611 / 1100	804 / 1450	889 / 1600	972 (Celsius) / 1750 (Fahrenheit)
XLH 170					
Natural	29 Sep.	9 Nov.	31 Jan.	9 Mar.	31 Mar.
Reach bypassed by Tailrace Tunnel	4 Nov.	25 Dec.	24 Feb.	20 Mar.	10 Apr.
XLH 120					
Natural	4 Oct.	19 Nov.	27 Feb.	26 Mar.	14 Apr.
Regulated with Average Temperatures	3 Nov.	7 Jan.	15 Mar.	8 Apr.	28 Apr.
Regulated with Plus 2°C Temperatures	3 Nov.	7 Jan.	15 Mar.	8 Apr.	28 Apr.
Regulated with Minus 2°C Temperatures	3 Nov.	7 Jan.	15 Mar.	8 Apr.	28 Apr.
XLH 30					
Natural	15 Oct.	11 Dec.	14 Mar.	7 Apr.	25 Apr.
Regulated with Average Temperatures	12 Oct.	2 Dec.	24 Feb.	18 Mar.	7 Apr.
Regulated with Plus 2°C Temperatures	2 Oct.	4 Nov.	22 Dec.	16 Jan.	7 Feb.
Regulated with Minus 2°C Temperatures	29 Oct.	17 Mar.	12 May	30 May	16 Jun.

PRELIMINARY

TABLE 6 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 15 August)
13.2 km TAILRACE TUNNEL

Location	Accumulated Degree Day 417 (Celsius) / 750 (Fahrenheit)	611 / 1100	806 / 1450	889 / 1600	972 / 1750
XLH 170					
Natural	24 Oct.	22 Dec.	20 Mar.	7 Apr.	22 Apr.
Reach bypassed by Tailrace Tunnel	23 Nov.	16 Jan.	17 Mar.	7 Apr.	28 Apr.
XLH 120					
Natural	30 Oct.	15 Jun.	2 Apr.	19 Apr.	4 May
Regulated with Average Temperatures	23 Nov.	5 Feb.	5 Apr.	26 Apr.	15 May
Regulated with Plus 2°C Temperatures	23 Nov.	5 Feb.	5 Apr.	26 Apr.	15 May
Regulated with Minus 2°C Temperatures	23 Nov.	5 Feb.	5 Apr.	26 Apr.	15 May
XLH 30					
Natural	8 Nov.	8 Feb.	11 Apr.	29 Apr.	14 May
Regulated with Average Temperatures	31 Oct.	16 Jan.	20 Mar.	8 Apr.	25 Apr.
Regulated with Plus 2°C Temperatures	18 Oct.	26 Nov.	20 Jun.	10 Feb.	29 Feb.
Regulated with Minus 2°C Temperatures	27 Dec.	14 Apr.	30 May	15 Jun.	1 Jul.

PRELIMINARY

TABLE 6 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 29 August)
13.2 km TAILRACE TUNNEL

Location	Accumulated Degree Day 417 (Celsius) / 750 (Fahrenheit)	611 / 1100	806 / 1450	889 / 1600	972 / 1750
XLH 170					
Natural	15 Nov.	17 Feb.	10 Apr.	25 Apr.	8 May
Reach bypassed by Tailrace Tunnel	11 Dec.	8 Feb.	3 Apr.	24 Apr.	13 May
XLH 120					
Natural	23 Nov.	2 Mar.	21 Apr.	5 May	19 May
Regulated with Average Temperatures	16 Dec.	28 Feb.	23 Apr.	12 May	30 May
Regulated with Plus 2°C Temperatures	16 Dec.	28 Feb.	23 Apr.	12 May	30 May
Regulated with Minus 2°C Temperatures	16 Dec.	28 Feb.	23 Apr.	12 May	30 May
XLH 30					
Natural	7 Dec.	11 Mar.	29 Apr.	14 May	29 May
Regulated with Average Temperatures	24 Nov.	19 Feb.	9 Apr.	26 Apr.	12 May
Regulated with Plus 2°C Temperatures	4 Nov.	22 Dec.	13 Feb.	2 Mar.	19 Mar.
Regulated with Minus 2°C Temperatures	2 Mar.	4 May	14 Jun.	29 Jun.	16 Jul.

PRELIMINARY

TABLE 6 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 12 September)
13.2 km TAILRACE TUNNEL

Location	Accumulated Degree Day 417 / 750	611 / 1100	806 / 1450	889 / 1600	972 / 1750 (Celsius / Fahrenheit)
XLH 170					
Natural	21 Dec.	19 Mar.	26 Apr.	9 May	21 May
Reach bypassed by Tailrace Tunnel	27 Dec.	27 Feb.	19 Apr.	9 May	27 May
XLH 120					
Natural	6 Jan.	29 Mar.	6 May	19 May	1 Jun.
Regulated with Average Temperatures	12 Jan.	19 Mar.	8 May	26 May	13 Jun.
Regulated with Plus 2°C Temperatures	12 Jan.	19 Mar.	8 May	26 May	13 Jun.
Regulated with Minus 2°C Temperatures	12 Jan.	19 Mar.	8 May	26 May	13 Jun.
XLH 30					
Natural	20 Jan.	3 Apr.	14 May	28 May	11 Jun.
Regulated with Average Temperatures	4 Jan.	13 Mar.	26 Apr.	12 May	27 May
Regulated with Plus 2°C Temperatures	24 Nov.	18 Jan.	4 Mar.	20 Mar.	4 Apr.
Regulated with Minus 2°C Temperatures	30 Mar.	20 May	27 Jun.	14 Jul.	29 Jul.

TABLE 6 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 26 September)
13.2 km TAILRACE TUNNEL

Location	Accumulated Degree Day 417 / 750	611 / 1100	806 / 1450	889 / 1600	972 / 1750 (Celsius / Fahrenheit)
XLH 170					
Natural	13 Feb.	8 Apr.	10 May	22 May	4 Jun.
Reach bypassed by Tailrace Tunnel	15 Jan.	15 Mar.	3 May	22 May	10 Jun.
XLH 120					
Natural	23 Feb.	17 Apr.	20 May	2 Jun.	15 Jun.
Regulated with Average Temperatures	5 Feb.	5 Apr.	21 May	8 Jun.	25 Jun.
Regulated with Plus 2°C Temperatures	5 Feb.	5 Apr.	21 May	8 Jun.	25 Jun.
Regulated with Minus 2°C Temperatures	5 Feb.	5 Apr.	21 May	8 Jun.	25 Jun.
XLH 30					
Natural	25 Feb.	21 Apr.	27 May	9 Jun.	24 Jun.
Regulated with Average Temperatures	7 Feb.	1 Apr.	11 May	26 May	9 Jun.
Regulated with Plus 2°C Temperatures	18 Dec.	10 Feb.	22 Mar.	5 Apr.	19 Apr.
Regulated with Minus 2°C Temperatures	19 Apr.	2 Jun.	10 Jul.	26 Jul.	-

TABLE 6 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 10 October)
13.2 km TAILRACE TUNNEL

Location	Accumulated Degree Day				
	417	611	806	889	972 (Celsius)
	750	1100	1450	1600	1750 (Fahrenheit)
XLH 170					
Natural	7 Mar.	20 Apr.	20 May	2 Jun.	15 Jun.
Reach bypassed by Tailrace Tunnel	31 Jan.	29 Mar.	15 May	2 Jun.	20 Jun.
XLH 120					
Natural	16 Mar.	28 Apr.	29 May	12 Jun.	25 Jun.
Regulated with Average Temperatures	23 Feb.	19 Apr.	1 Jun.	19 Jun.	6 Jul.
Regulated with Plus 2°C Temperatures	23 Feb.	19 Apr.	1 Jun.	19 Jun.	6 Jul.
Regulated with Minus 2°C Temperatures	23 Feb.	19 Apr.	1 Jun.	19 Jun.	6 Jul.
XLH 30					
Natural	16 Mar.	2 May	5 Jun.	20 Jun.	3 Jul.
Regulated with Average Temperatures	29 Feb.	16 Apr.	23 May	7 Jun.	21 Jun.
Regulated with Plus 2°C Temperatures	13 Jan.	1 Mar.	6 Apr.	19 Apr.	3 May
Regulated with Minus 2°C Temperatures	3 May	13 Jun.	21 Jul.	-	-

TABLE 6 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 24 October)
13.2 km TAILRACE TUNNEL

Location	Accumulated Degree Day 417 / 750	611 / 1100	808 / 1450	889 / 1600	972 / 1750 (Celsius / Fahrenheit)
XLH 170					
Natural	27 Mar.	1 May	30 May	13 Jun.	25 Jun.
Reach bypassed by Tailrace Tunnel	20 Feb.	13 Apr.	28 May	16 Jun.	3 Jul.
XLH 120					
Natural	2 Apr.	9 May	9 Jun.	25 Jun.	4 Jul.
Regulated with Average Temperatures	12 Mar.	2 May	14 Jun.	30 Jun.	19 Jul.
Regulated with Plus 2°C Temperatures	12 Mar.	2 May	14 Jun.	30 Jun.	19 Jul.
Regulated with Minus 2°C Temperatures	12 Mar.	2 May	14 Jun.	30 Jun.	19 Jul.
XLH 30					
Natural	3 Apr.	13 May	15 Jun.	29 Jun.	13 Jul.
Regulated with Average Temperatures	19 Mar.	30 Apr.	5 Jun.	19 Jun.	2 Jul.
Regulated with Plus 2°C Temperatures	5 Feb.	18 Mar.	20 Apr.	3 May	17 May
Regulated with Minus 2°C Temperatures	15 May	23 Jun.	30 Jul.	-	-

PRELIMINARY

TABLE 6 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 7 November)
13.2 km TAILRACE TUNNEL

Location	Accumulated Degree Day 417 / 750	611 / 1100	806 / 1450	889 / 1600	972 / 1750 (Celsius / Fahrenheit)
XLH 170					
Natural	9 Apr.	11 May	9 Jun.	23 Jun.	4 Jul.
Reach bypassed by Tailrace Tunnel	7 Mar.	26 Apr.	9 Jun.	27 Jun.	16 Jul.
XLH 120					
Natural	15 Apr.	18 May	19 Jun.	1 Jul.	13 Jul.
Regulated with Average Temperatures	27 Mar.	14 May	25 Jun.	13 Jul.	-
Regulated with Plus 2°C Temperatures	27 Mar.	14 May	25 Jun.	13 Jul.	-
Regulated with Minus 2°C Temperatures	27 Mar.	14 May	25 Jun.	13 Jul.	-
XLH 30					
Natural	16 Apr.	23 May	25 Jun.	8 Jul.	22 Jul.
Regulated with Average Temperatures	2 Apr.	11 May	14 Jun.	28 Jun.	13 Jul.
Regulated with Plus 2°C Temperatures	22 Feb.	31 Mar.	2 May	15 May	28 May
Regulated with Minus 2°C Temperatures	24 May	1 Jul.	-	-	-

PRELIMINARY

TABLE 6 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 21 November)
13.2 km TAILRACE TUNNEL

Location	Accumulated Degree Day					
	417	611	804	889	972	(Celsius)
	750	1100	1450	1600	1750	(Fahrenheit)
XLH 170						
Natural	19 Apr.	19 May	19 Jun.	30 Jun.	11 Jul.	
Reach bypassed by Tailrace Tunnel	22 Mar.	9 May	20 Jun.	9 Jul.	28 Jul.	
XLH 120						
Natural	25 Apr.	27 May	27 Jun.	8 Jul.	20 Jul.	
Regulated with Average Temperatures	10 Apr.	25 May	5 Jul.	24 Jul.	-	
Regulated with Plus 2°C Temperatures	10 Apr.	25 May	5 Jul.	24 Jul.	-	
Regulated with Minus 2°C Temperatures	10 Apr.	25 May	5 Jul.	24 Jul.	-	
XLH 30						
Natural	27 Apr.	31 May	3 Jul.	17 Jul.	29 Jul.	
Regulated with Average Temperatures	12 Apr.	20 May	22 Jun.	6 Jul.	21 Jul.	
Regulated with Plus 2°C Temperatures	7 Mar.	11 Apr.	12 May	25 May	7 Jun.	
Regulated with Minus 2°C Temperatures	31 May	7 Jul.	-	-	-	

TABLE 6 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 DATA
(from 5 December)
13.2 km TAILRACE TUNNEL

Location	Accumulated Degree Day					
	417	611	806	889	972	(Celsius)
	750	1100	1450	1600	1750	(Fahrenheit)
XLH 170						
Natural	25 Apr.	24 May	24 Jun.	5 Jul.	16 Jul.	
Reach bypassed by Tailrace Tunnel	4 Apr.	20 May	1 Jul.	20 Jul.	-	
XLH 120						
Natural	30 Apr.	31 May	1 Jul.	13 Jul.	24 Jul.	
Regulated with Average Temperatures	21 Apr.	4 Jun.	16 Jul.	-	-	
Regulated with Plus 2°C Temperatures	21 Apr.	4 Jun.	16 Jul.	-	-	
Regulated with Minus 2°C Temperatures	21 Mar.	4 Jun.	16 Jul.	-	-	
XLH 30						
Natural	3 May	6 Jun.	8 Jul.	22 Jul.	-	
Regulated with Average Temperatures	20 Apr.	26 May	28 Jun.	13 Jul.	27 Jul.	
Regulated with Plus 2°C Temperatures	18 Mar.	20 Apr.	21 May	2 Jun.	15 Jun.	
Regulated with Minus 2°C Temperatures	3 Jun.	10 Jul.	-	-	-	

PRELIMINARY

TABLE 7

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 BREW CREEK DATA
SENSITIVITY TEST AT XLH 170 WHEN BYPASSED

Location	Accumulated Degree Day				
	417	611	806	889	972 (Celsius)
	750	1100	1450	1600	1750 (Fahrenheit)
FROM 1 AUGUST					
Natural Temperatures	4 Nov.	25 Dec.	24 Feb.	20 Mar.	10 Apr.
Natural Temperatures Plus 2°C	3 Oct.	5 Nov.	8 Dec.	23 Dec.	7 Jan.
Natural Temperatures Minus 2°C	15 Mar.	12 Jun.	-	-	-
FROM 15 AUGUST					
Natural Temperatures	23 Nov.	16 Jan.	17 Mar.	7 Apr.	28 Apr.
Natural Temperatures Plus 2°C	20 Oct.	22 Nov.	25 Dec.	10 Jan.	27 Jan.
Natural Temperatures Minus 2°C	8 Apr.	27 Jun.	-	-	-
FROM 29 AUGUST					
Natural Temperatures	11 Dec.	8 Feb.	3 Apr.	24 Apr.	13 May
Natural Temperatures Plus 2°C	5 Nov.	9 Dec.	13 Jan.	29 Jan.	15 Feb.
Natural Temperatures Minus 2°C	27 Apr.	15 Jul.	-	-	-

PRELIMINARY

TABLE 7 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 BREW CREEK DATA
SENSITIVITY TEST AT XLH 170 WHEN BYPASSED

Location	Accumulated Degree Day				
	417	611	806	889	972 (Celsius)
	750	1100	1450	1600	1750 (Fahrenheit)
FROM 12 SEPTEMBER					
Natural Temperatures	27 Dec.	27 Feb.	19 Apr.	9 May	27 May
Natural Temperatures Plus 2°C	20 Nov.	24 Dec.	30 Jan.	16 Feb.	2 Mar.
Natural Temperatures Minus 2°C	12 May	28 Jul.	-	-	-
FROM 26 SEPTEMBER					
Natural Temperatures	15 Jan.	15 Mar.	3 May	22 May	10 Jun.
Natural Temperatures Plus 2°C	6 Dec.	9 Jan.	17 Feb.	3 Mar.	18 Mar.
Natural Temperatures Minus 2°C	24 May	-	-	-	-
FROM 10 OCTOBER					
Natural Temperatures	31 Jan.	29 Mar.	15 May	12 Jun.	25 Jun.
Natural Temperatures Plus 2°C	19 Dec.	25 Jan.	2 Mar.	18 Mar.	1 Apr.
Natural Temperatures Minus 2°C	3 Jun.	-	-	-	-

PRELIMINARY

TABLE 7 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 BREW CREEK DATA
SENSITIVITY TEST AT XLH 170 WHEN BYPASSED

Location	Accumulated Degree Day					
	417	611	806	889	972	(Celsius)
	750	1100	1450	1600	1750	(Fahrenheit)
FROM 24 OCTOBER						
Natural Temperatures	20 Feb.	13 Apr.	28 May	16 Jun.	3 Jul.	
Natural Temperatures Plus 2°C	4 Jan.	11 Feb.	18 Mar.	2 Apr.	16 Apr.	
Natural Temperatures Minus 2°C	15 Jun.	-	-	-	-	
FROM 7 NOVEMBER						
Natural Temperatures	7 Mar.	26 Apr.	9 Jun.	27 Jun.	16 Jul.	
Natural Temperatures Plus 2°C	20 Jan.	27 Feb.	2 Apr.	16 Apr.	29 Apr.	
Natural Temperatures Minus 2°C	25 Jun.	-	-	-	-	
FROM 21 NOVEMBER						
Natural Temperatures	22 Mar.	9 May	20 Jun.	9 Jul.	28 Jul.	
Natural Temperatures Plus 2°C	5 Feb.	13 Mar.	15 Apr.	29 Apr.	12 May	
Natural Temperatures Minus 2°C	4 Jul.	-	-	-	-	

PRELIMINARY

TABLE 7 - (Cont'd)

DATES FOR DEGREE-DAY ACCUMULATIONS WITH 1983 BREW CREEK DATA
SENSITIVITY TEST AT XLH 170 WHEN BYPASSED

Location	Accumulated Degree Day					
	417	611	806	889	972	(Celsius)
	750	1100	1450	1600	1750	(Fahrenheit)
FROM 5 DECEMBER						
Natural Temperatures	4 Apr.	20 May	1 Jul.	20 Jul.	-	
Natural Temperatures Plus 2°C	21 Feb.	27 Mar.	28 Apr.	11 May	24 May	
Natural Temperatures Minus 2°C	15 Jul.	-	-	-	-	

PRELIMINARY

T-WSC TRAGEDY CANYON

Washington Canyon Project

T-BCH-XLH100

XLN 180

T-BCH-XLH170

XLN170

XLH165

XLH154

XLH146

XLN 160

XLH145

2.7 km Tailrace Tunnel

3.2 km Alternative Tailrace Tunnel

T-BCH NEWAKWA R.

T-WSC-MOUTH

XLN 140

T-BCH-XLH140

T-BCH SCAR CR.

BCH SCAR CR. SOLARIMETER

XLH 130

XLH120

XLH110

T-BCH 20 MILE

XLH90

XLH100

XLH80

T-BCH XLH70

XLH70

XLH 40

XLH50

XLH30

XLH10

BCH BREW CR. MET. STATION

T-BCH BREW CR.

WHITE MANTLE RANGE

STUDY AREA

KEY PLAN

LEGEND:

T-BCH B.C. HYDRO RYAN THERMOGRAPH

T-WSC WATER SURVEY OF CANADA TEMPERATURE RECORDER

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

HOMATHKO DEVELOPMENT

HOMATHKO RIVER STUDIES

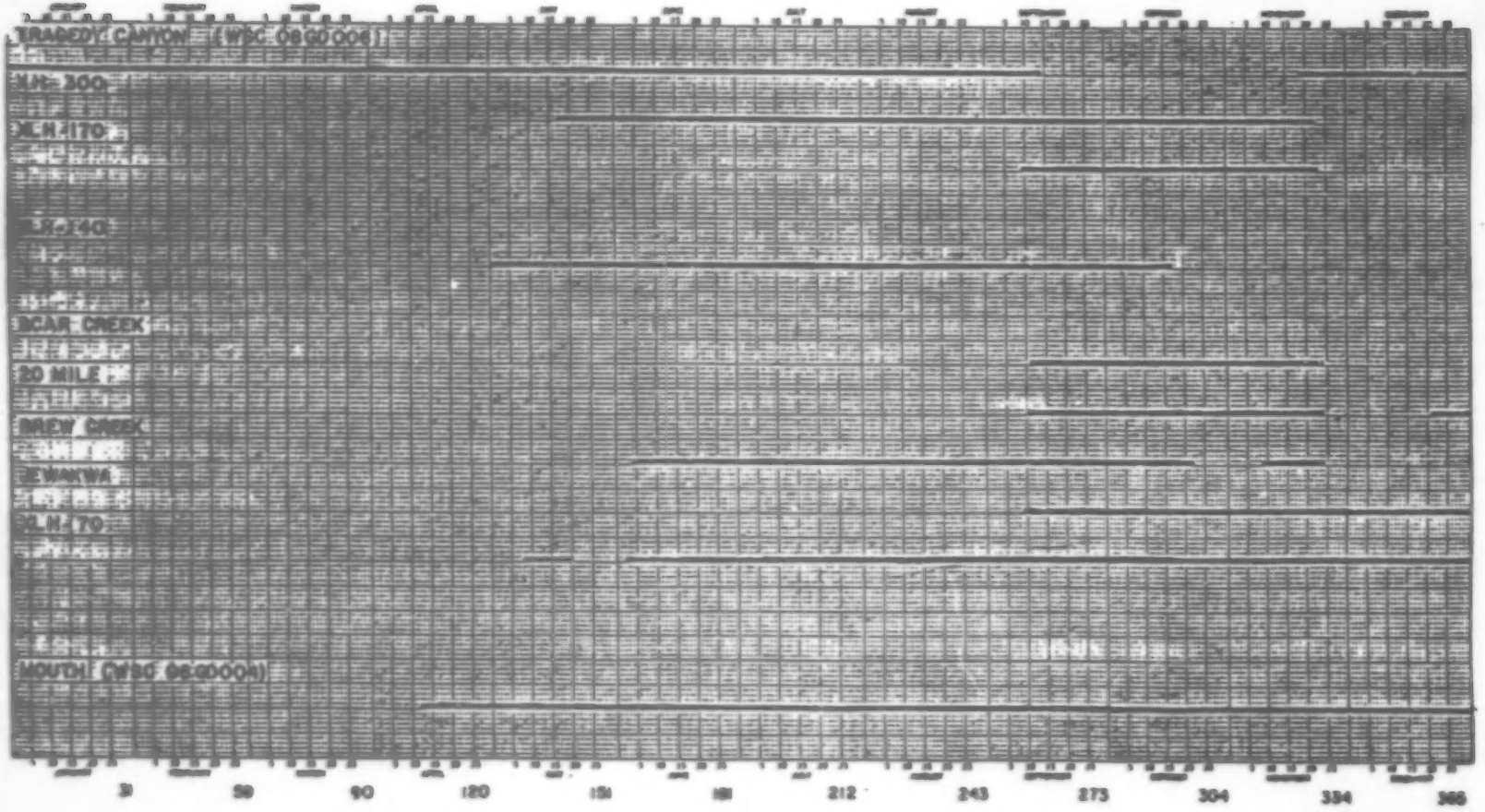
LOWER HOMATHKO RIVER

KEY PLAN

DATE 15 MAY, 1984	FIG. 1
DRWN RKPC	DWG No. 704-C14-8474

HOMATHKO DEVELOPMENT

PERIOD OF AVAILABLE RECORD FOR WATER TEMPERATURE DATA



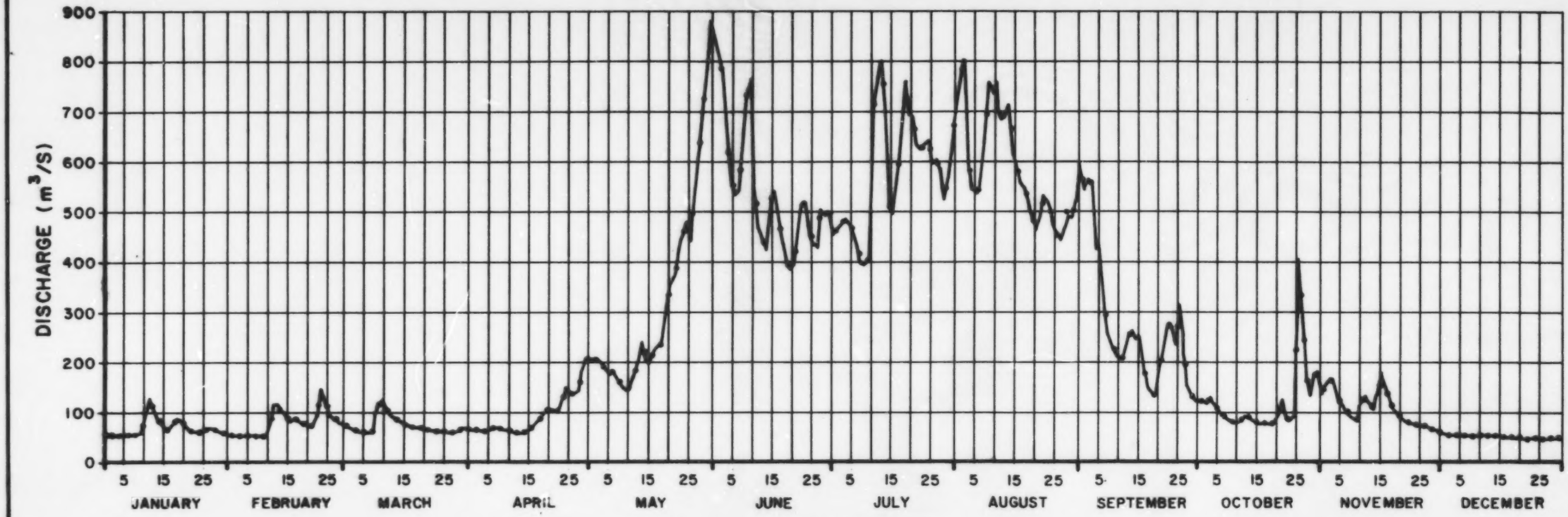
1983

NOTE:

THIS IS THE EXTENT OF DATA AVAILABLE DURNING THE STUDY.

ALL FIELD DATA WAS LATER PROCESSED AND FILED IN DATA APPENDIX (REPORT H1733)

FIG. 2



LEGEND:

- • *Computed Discharge*
- —— *Observed Discharge*

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

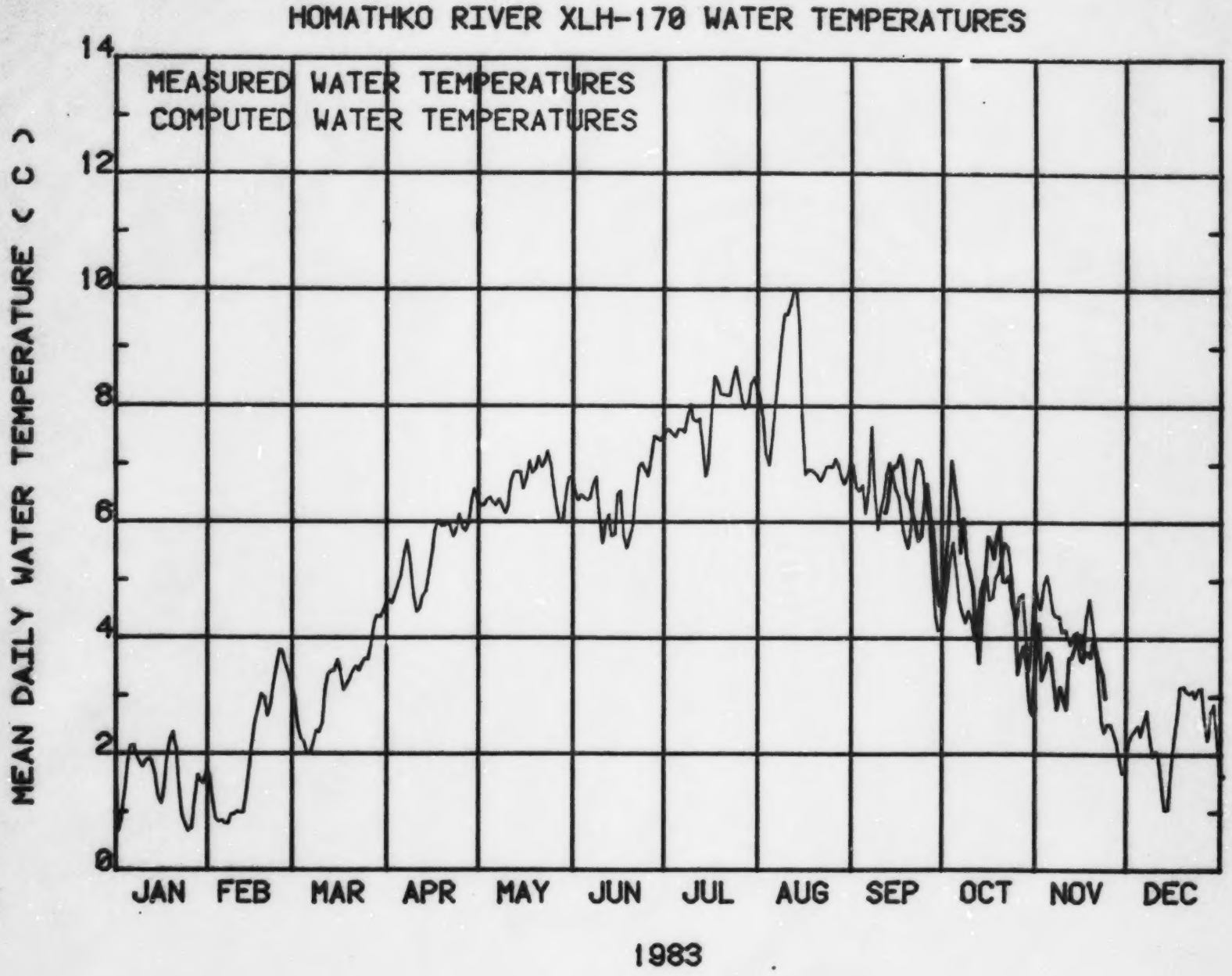
NOMATHKO DEVELOPMENT – THERMAL REGIME STUDY

NOMATHKO RIVER NEAR THE MOUTH

COMPARISON OF COMPUTED AND [redacted]

DATE OCT 1984	FIG. 3
DWN ASD	DWG. No. 704-014-0677

REPORT No. 11725


HOMATHKO RIVER XLH-170 WATER TEMPERATURES
MEASURED WATER TEMPERATURES
COMPUTED WATER TEMPERATURES
MEAN DAILY WATER TEMPERATURE (C)
14
12
10
8
6
4
2
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1983

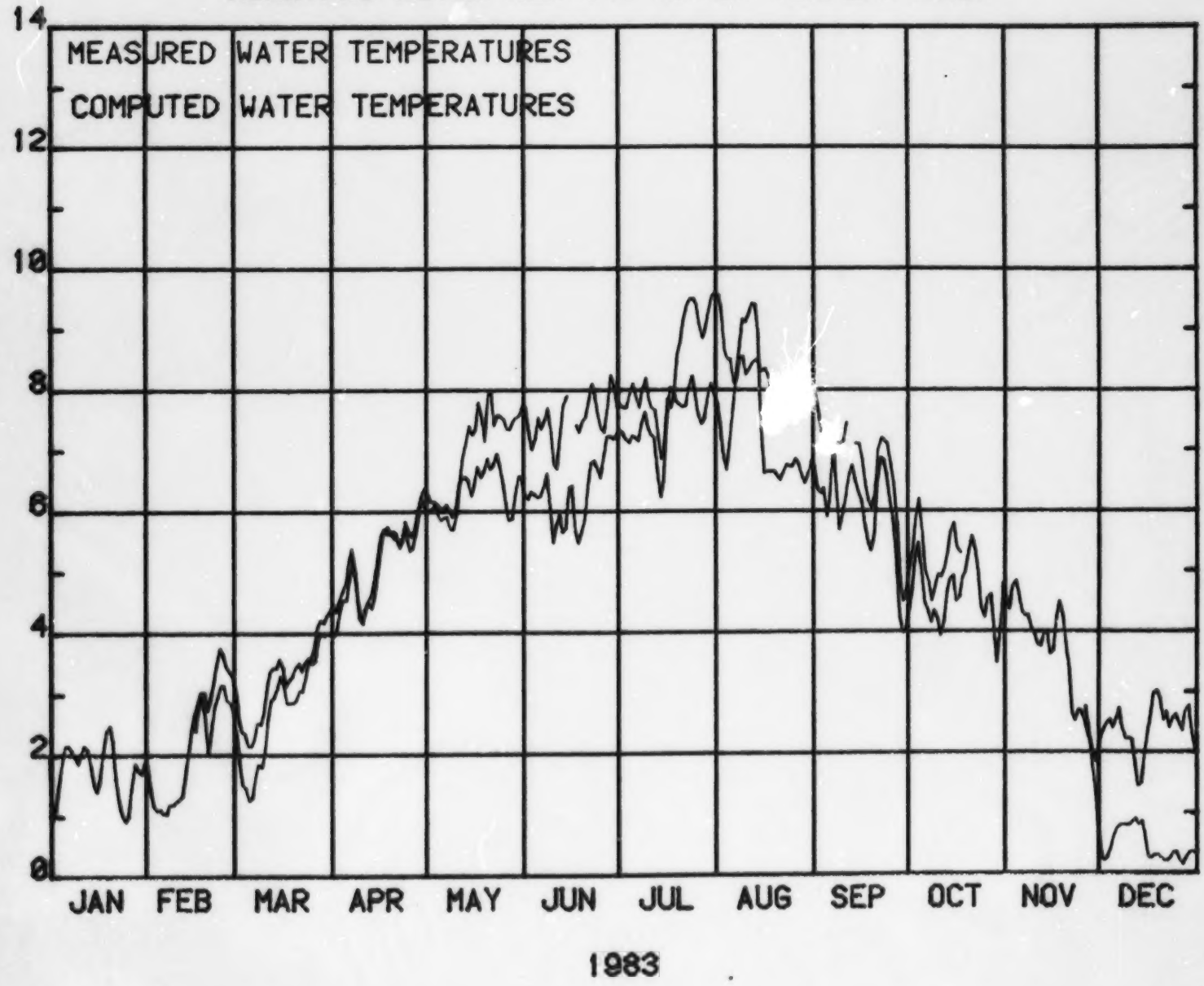

HOMATHKO RIVER XLH-140 WATER TEMPERATURES
MEASURED WATER TEMPERATURES
COMPUTED WATER TEMPERATURES
MEAN DAILY WATER TEMPERATURE (C)
14
12
10
8
6
4
2
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1983

FIG. 5

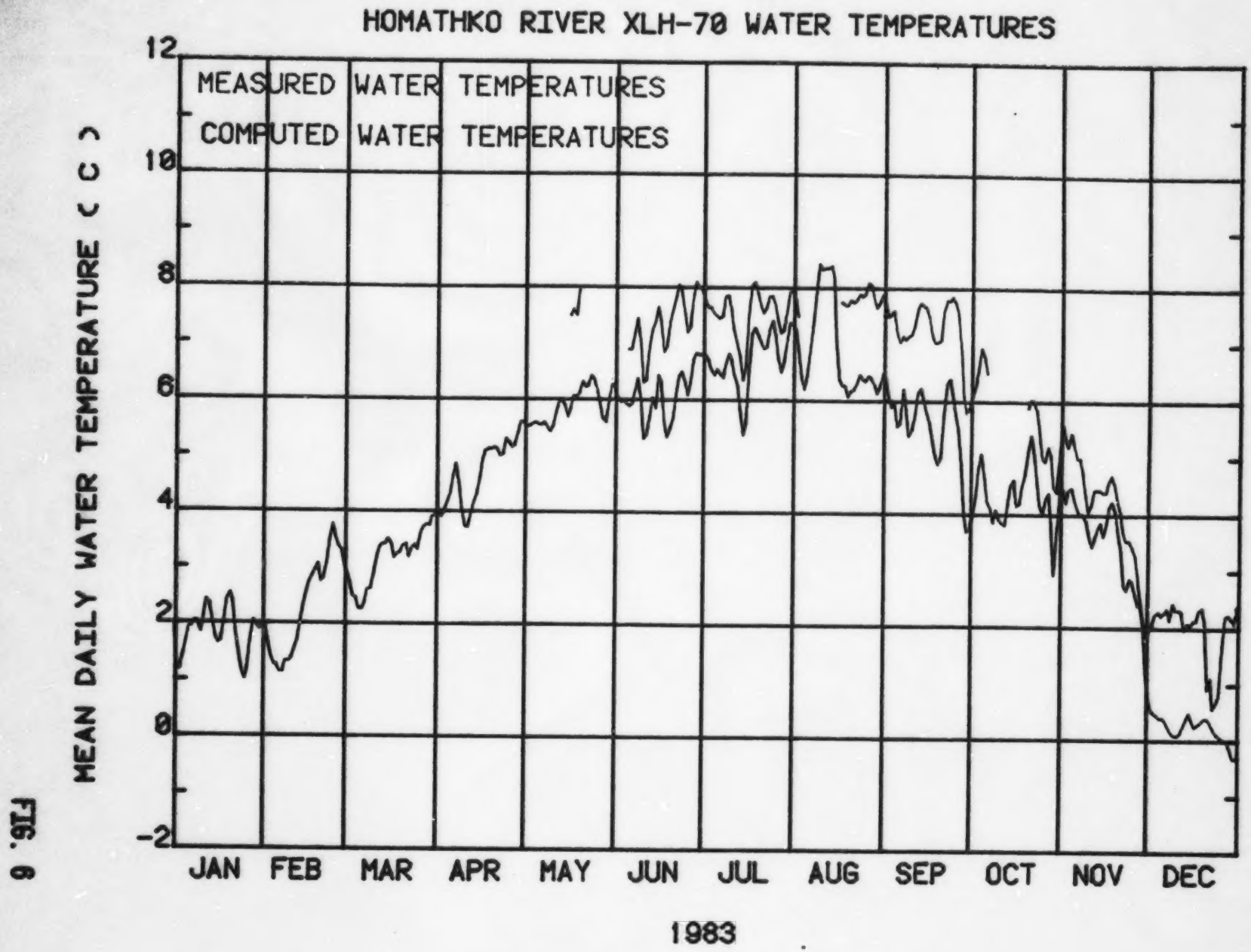

HOMATHKO RIVER XLH-70 WATER TEMPERATURES
MEASURED WATER TEMPERATURES
COMPUTED WATER TEMPERATURES
MEAN DAILY WATER TEMPERATURE (C)
12
10
8
6
4
2
0
-2
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1983

FIG. 8

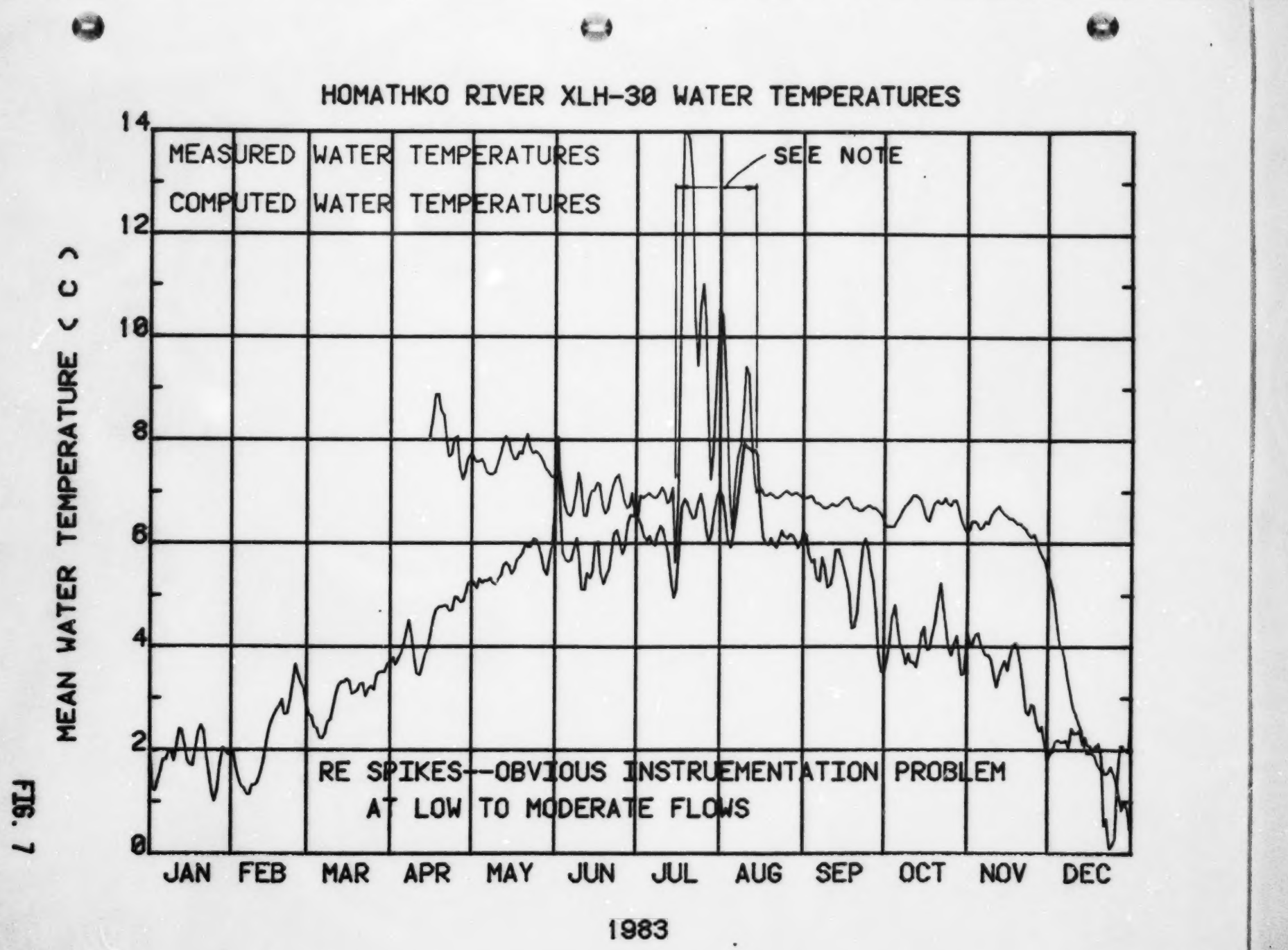

HOMATHKO RIVER XLH-30 WATER TEMPERATURES
MEASURED WATER TEMPERATURES
COMPUTED WATER TEMPERATURES
SEE NOTE
MEAN WATER TEMPERATURE (C)
14
12
10
8
6
4
2
0
RE SPIKES--OBVIOUS INSTRUEMENTATION PROBLEM
AT LOW TO MODERATE FLOWS
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
1983

FIG. 7

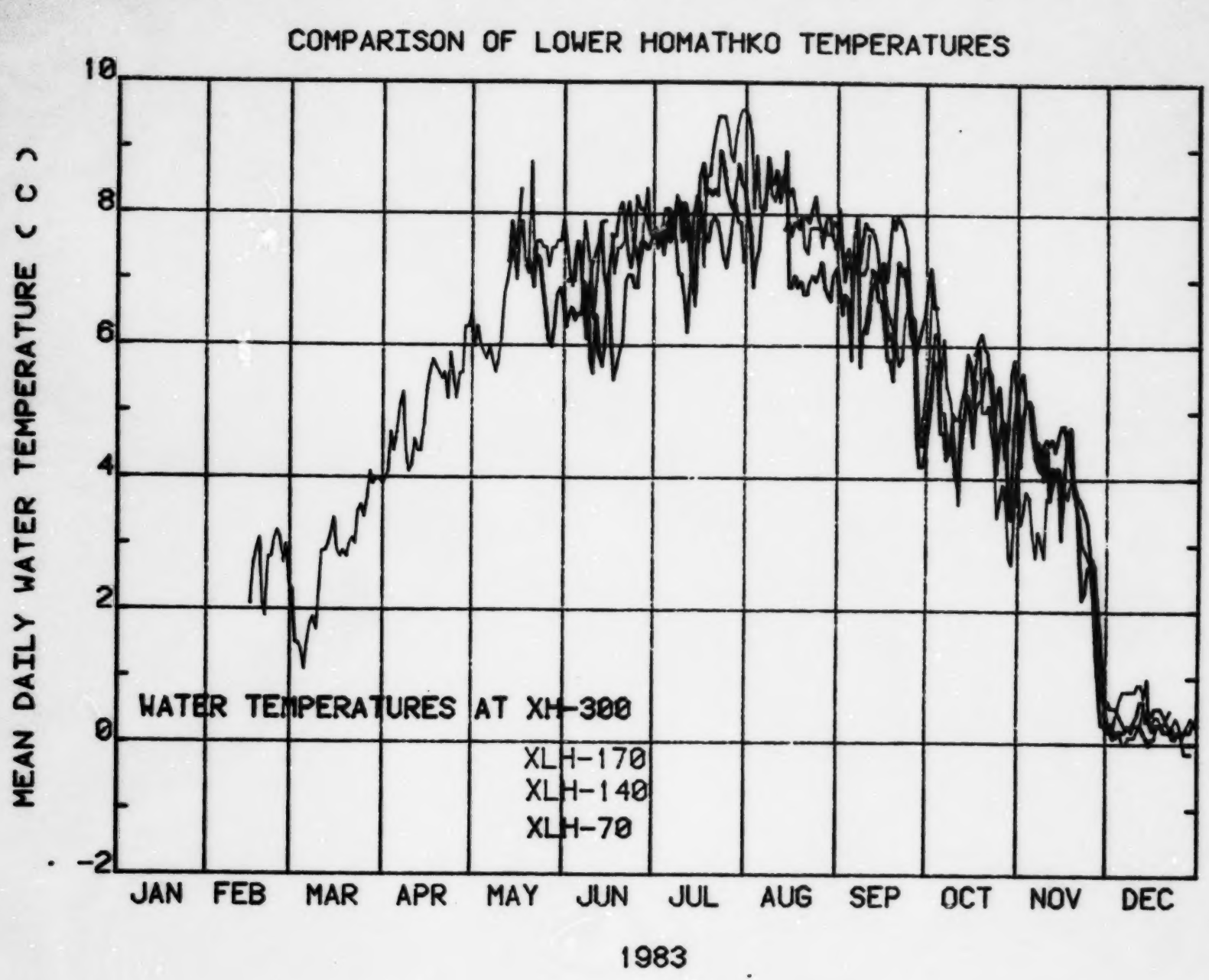
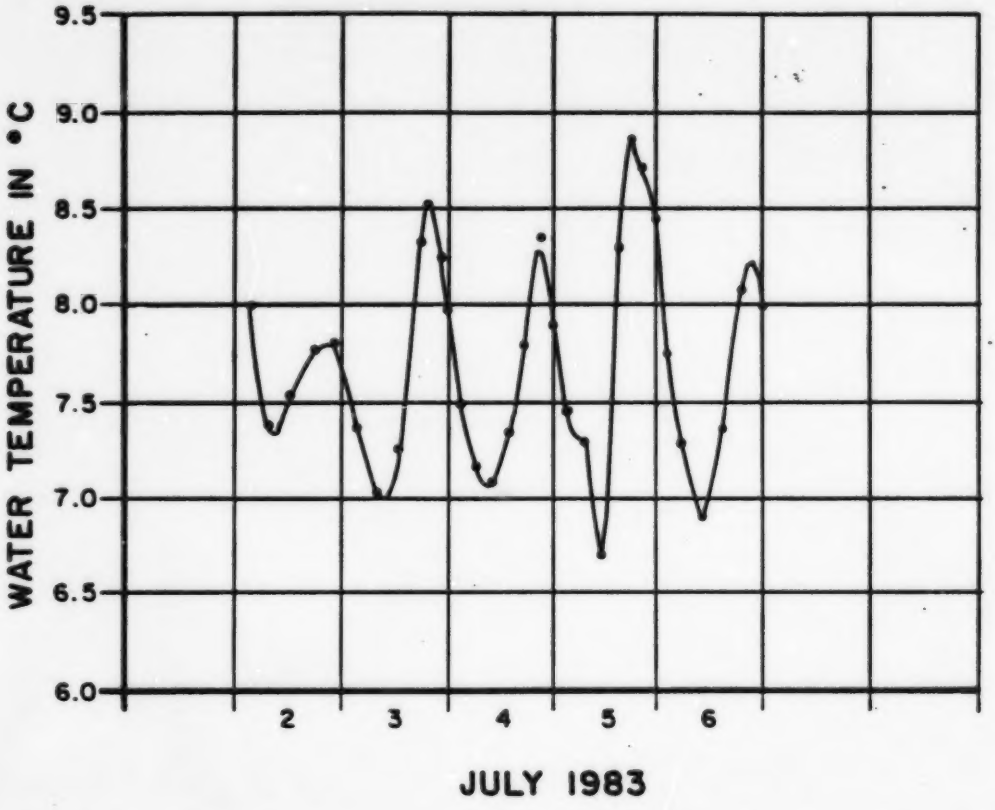

COMPARISON OF LOWER HOMATHKO TEMPERATURES
MEAN DAILY WATER TEMPERATURE (C)
10
8
6
4
2
0
-2
WATER TEMPERATURES AT XH-300
XLH-170
XLH-140
XLH-70
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1983

FIG. 8

DIURNAL WATER TEMPERATURE AND DISCHARGE FLUCTUATIONS
FOR
HOMATHKO RIVER AT XH300



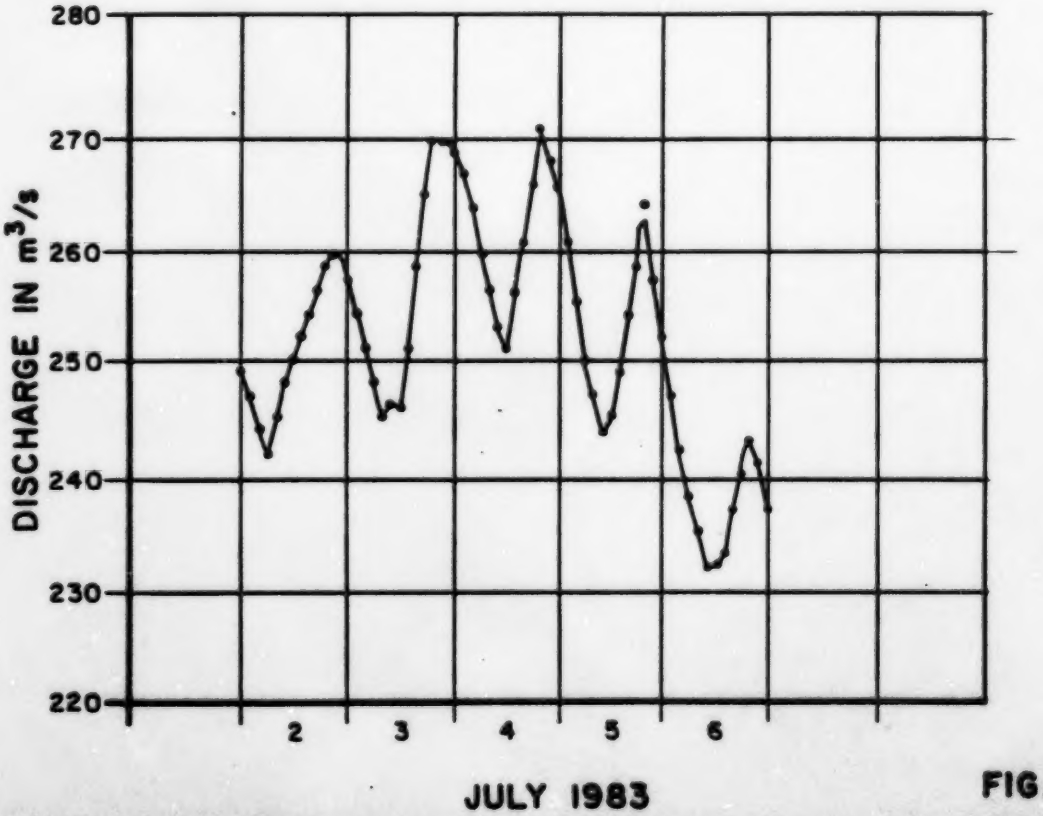
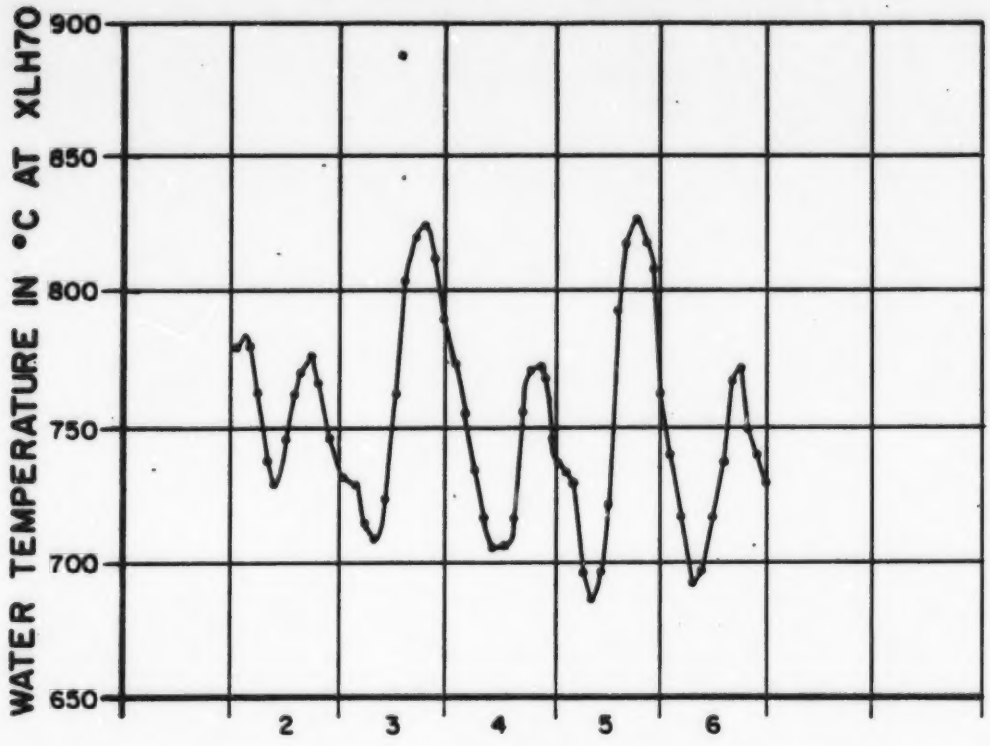


FIG. 9

DIURNAL WATER TEMPERATURE AND DISCHARGE FLUCTUATIONS
FOR
HOMATHKO RIVER AT XLH70



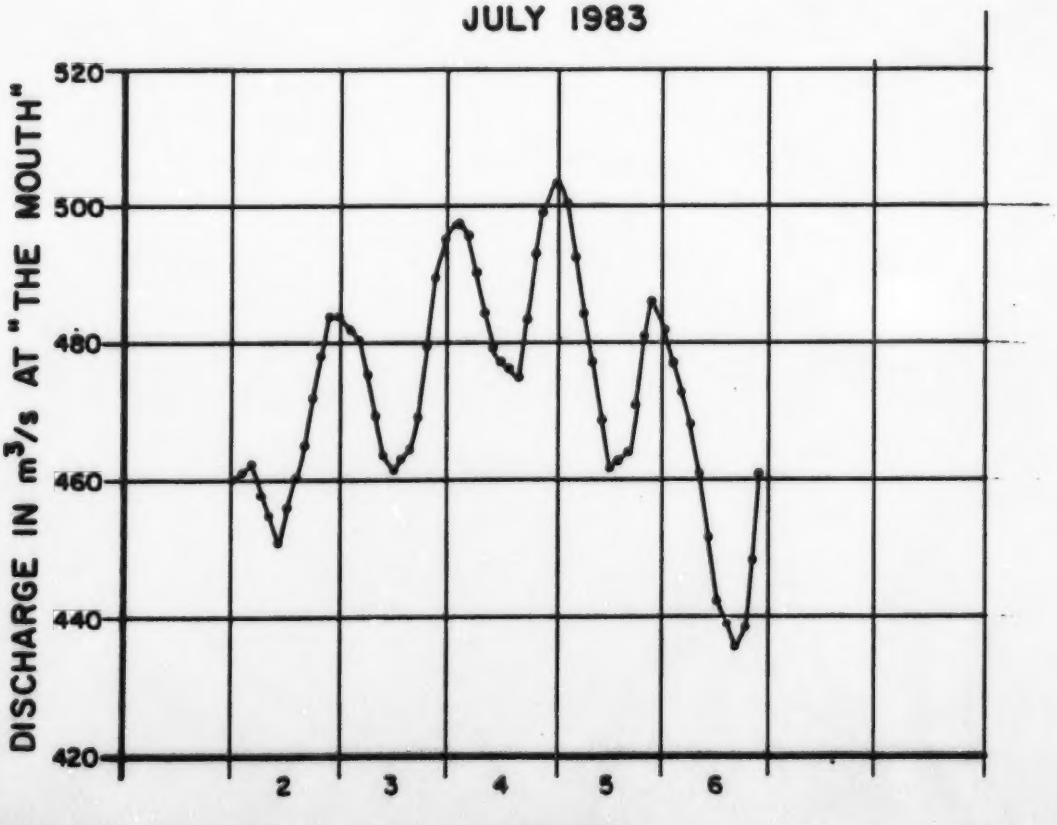


FIG. 10

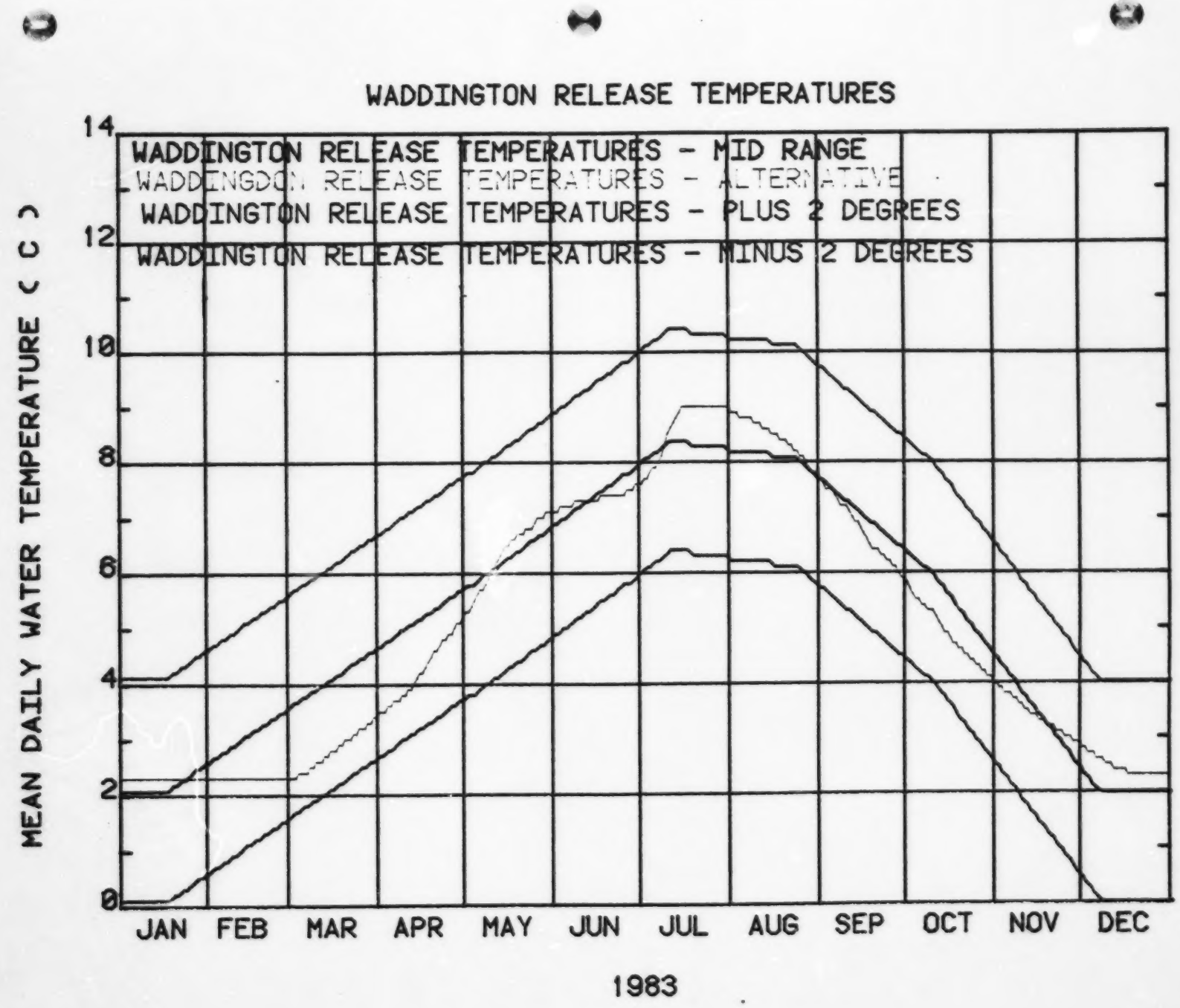

WADDINGTON RELEASE TEMPERATURES
WADDINGTON RELEASE TEMPERATURES - MID RANGE
WADDINGTON RELEASE TEMPERATURES - ALTERNATIVE
WADDINGTON RELEASE TEMPERATURES - PLUS 2 DEGREES
WADDINGTON RELEASE TEMPERATURES - MINUS 2 DEGREES
MEAN DAILY WATER TEMPERATURE (C)
14
12
10
8
6
4
2
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1983

FIG. 11

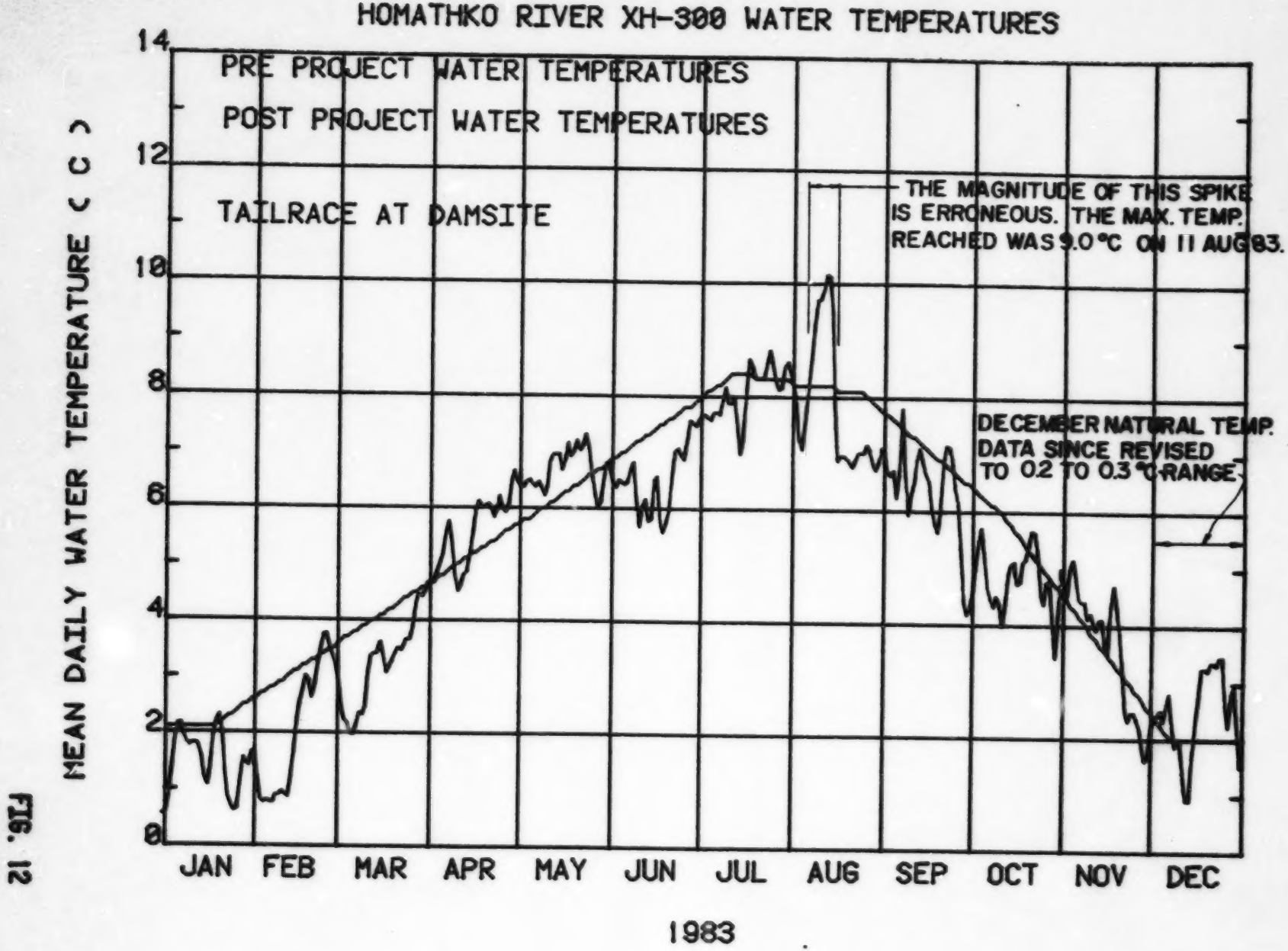

HOMATHKO RIVER XH-300 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES
TAILRACE AT DAMSITE
THE MAGNITUDE OF THIS SPIKE IS ERRONEOUS. THE MAX. TEMP. REACHED WAS 9.0 °C ON 11 AUG 83.
DECEMBER NATURAL TEMP. DATA SINCE REVISED TO 0.2 TO 0.3 °C RANGE.
MEAN DAILY WATER TEMPERATURE (C)
14
12
10
8
6
4
2
0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
1983

FIG. 12

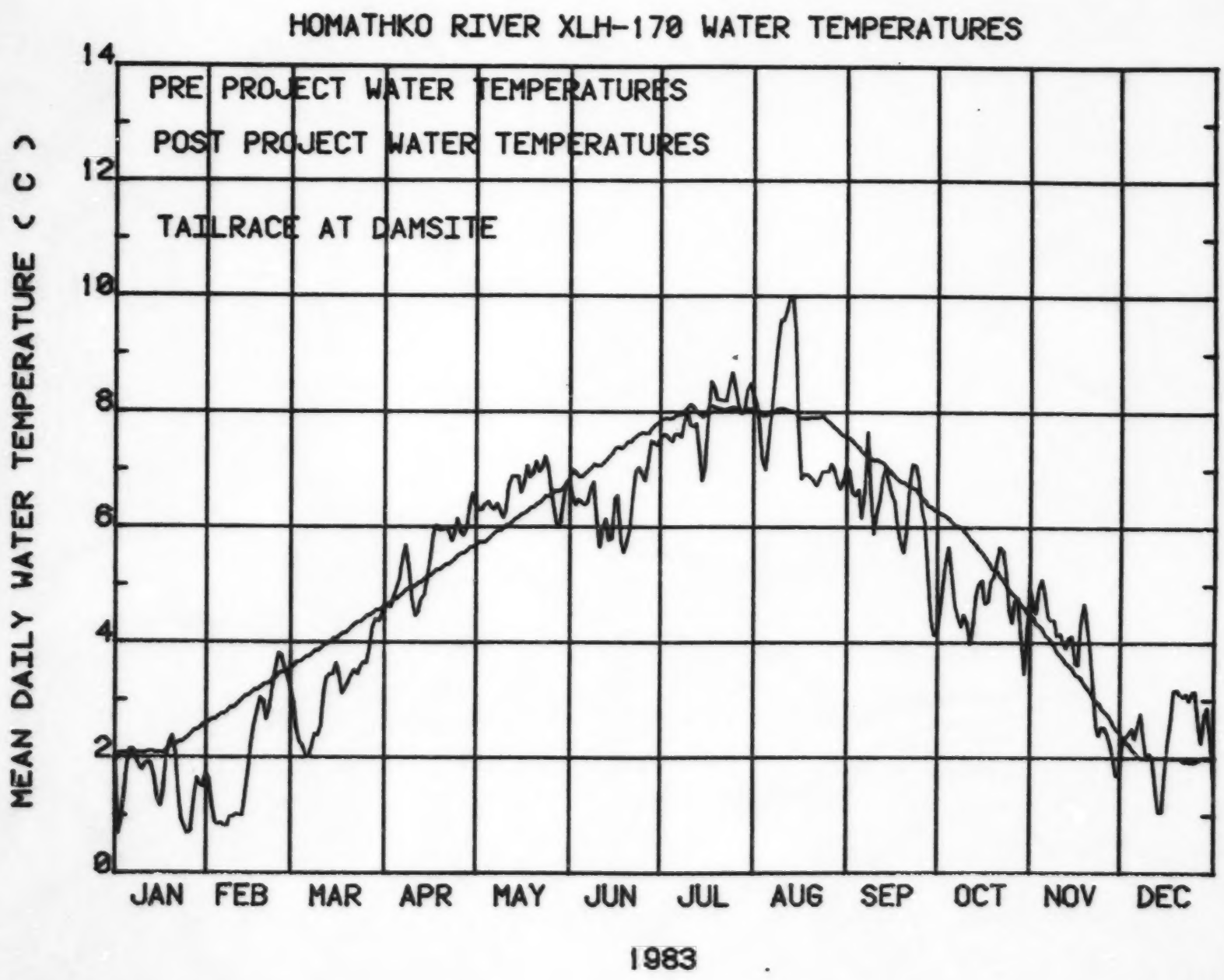

HOMATHKO RIVER XLH-170 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES
TAILRACE AT DAMSITE
MEAN DAILY WATER TEMPERATURE (C)
14
12
10
8
6
4
2
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1983

FIG. 13

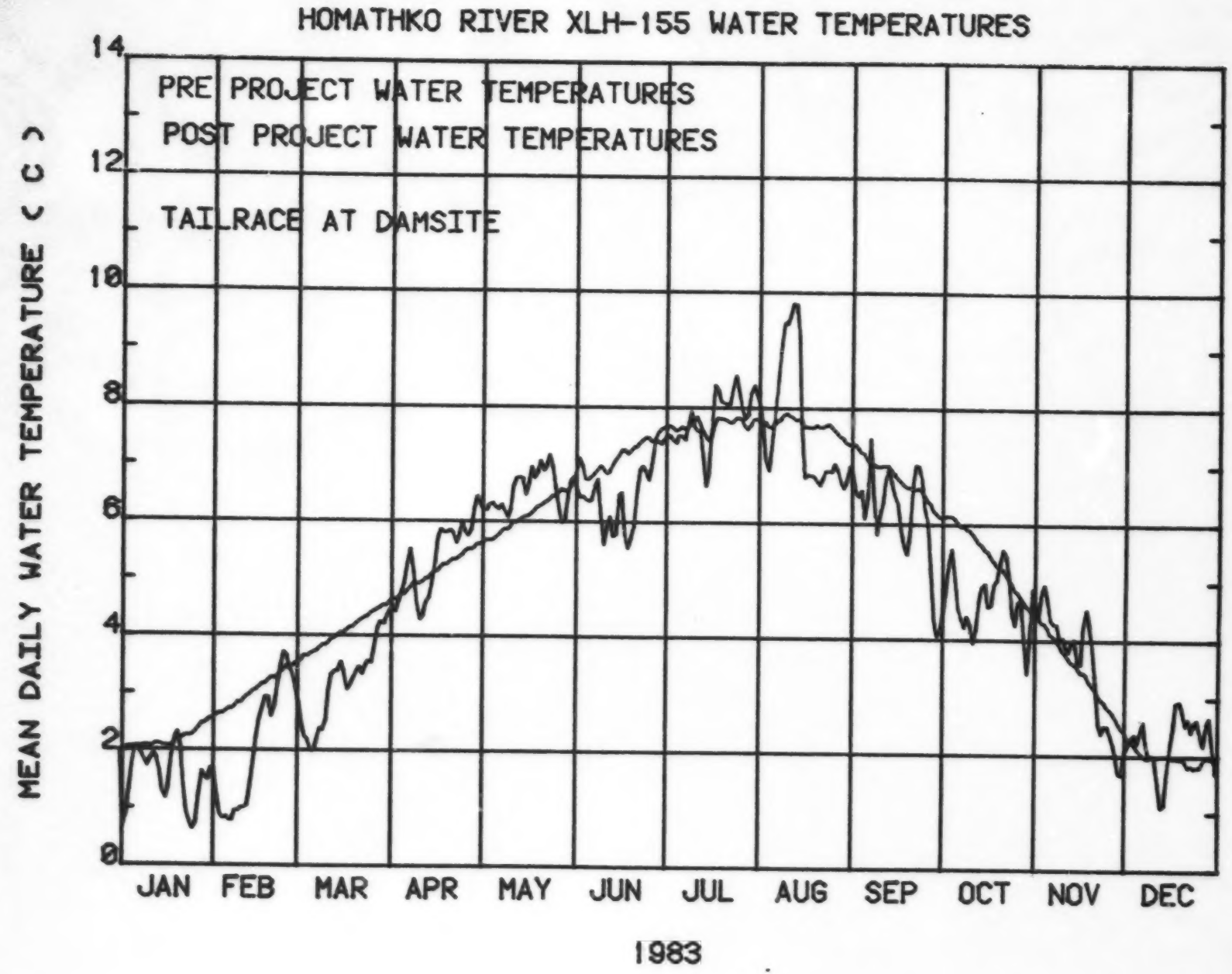

HOMATHKO RIVER XLH-155 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES
TAILRACE AT DAMSITE
MEAN DAILY WATER TEMPERATURE (C)
14
12
10
8
6
4
2
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1983

FIG. 14

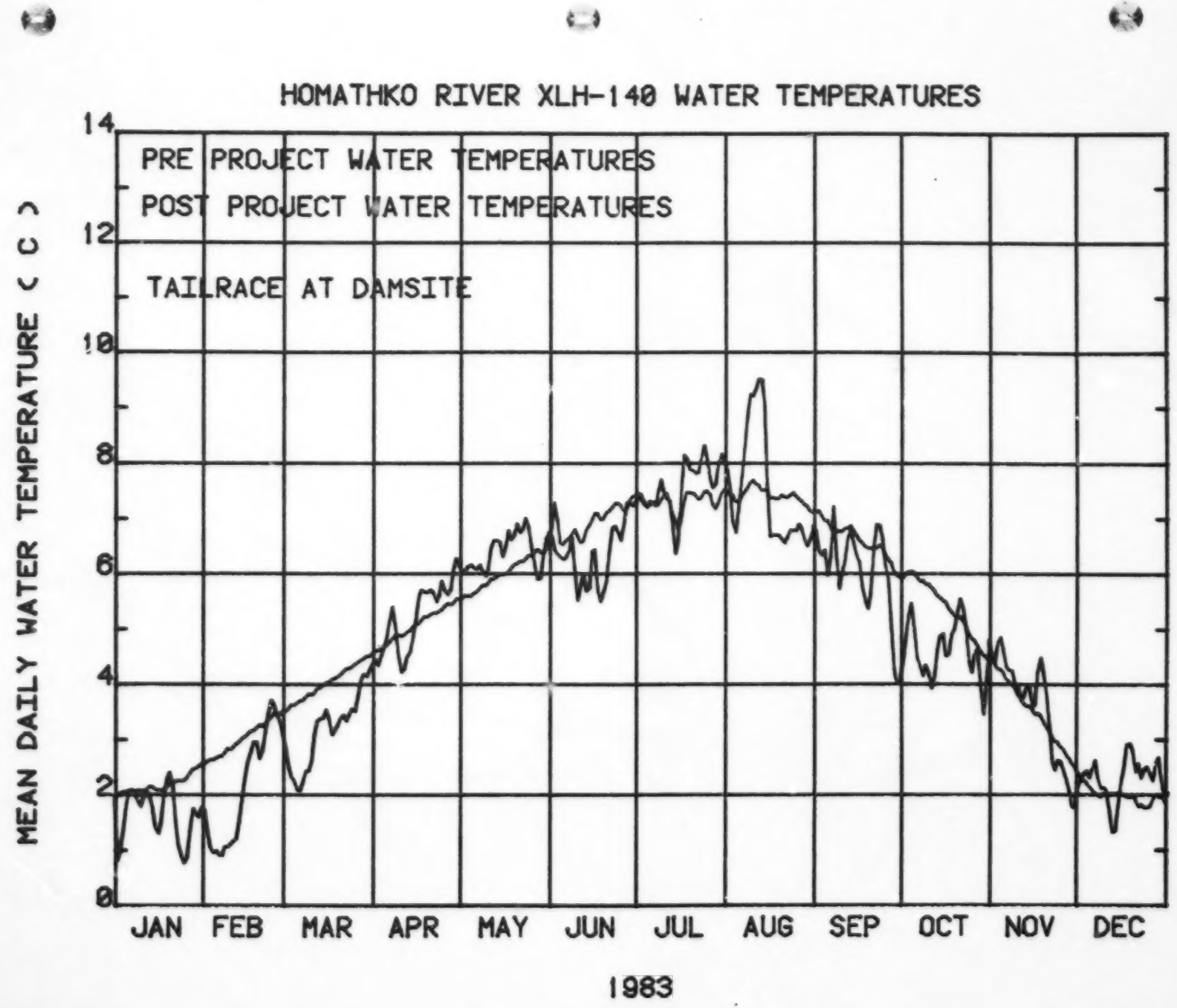

HOMATHKO RIVER XLH-140 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES
TAILRACE AT DAMSITE
MEAN DAILY WATER TEMPERATURE (C)
14
12
10
8
6
4
2
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1983

FIG. 15

HOMATHKO RIVER XLH-120 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES
TAILRACE AT DAMSITE
MEAN DAILY WATER TEMPERATURE (C)
0
2
4
6
8
10
12
14
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
1983

FIG. 16

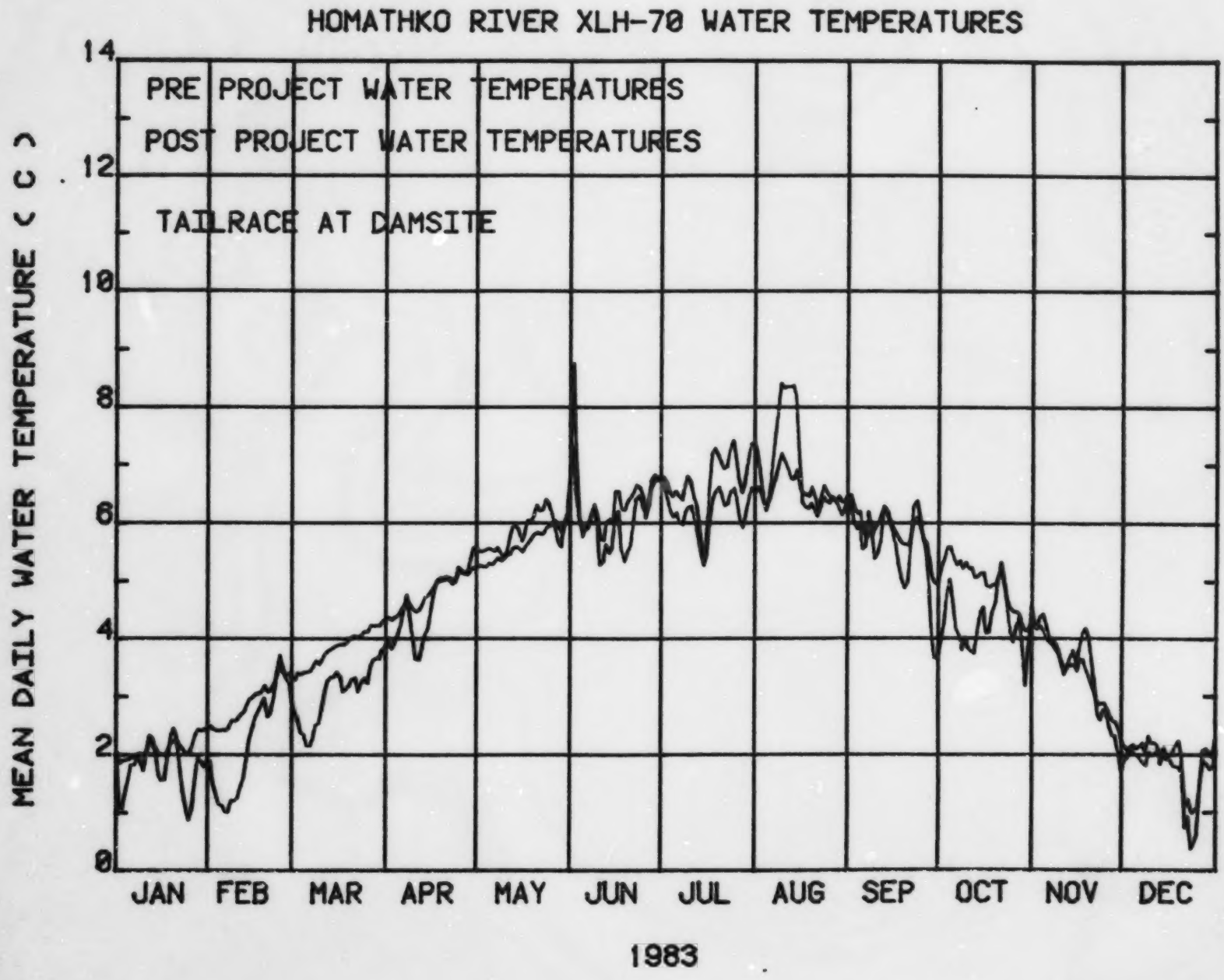

HOMATHKO RIVER XLH-70 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES
TAILRACE AT DAMSITE
MEAN DAILY WATER TEMPERATURE (C)
14
12
10
8
6
4
2
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1983

FIG. 17

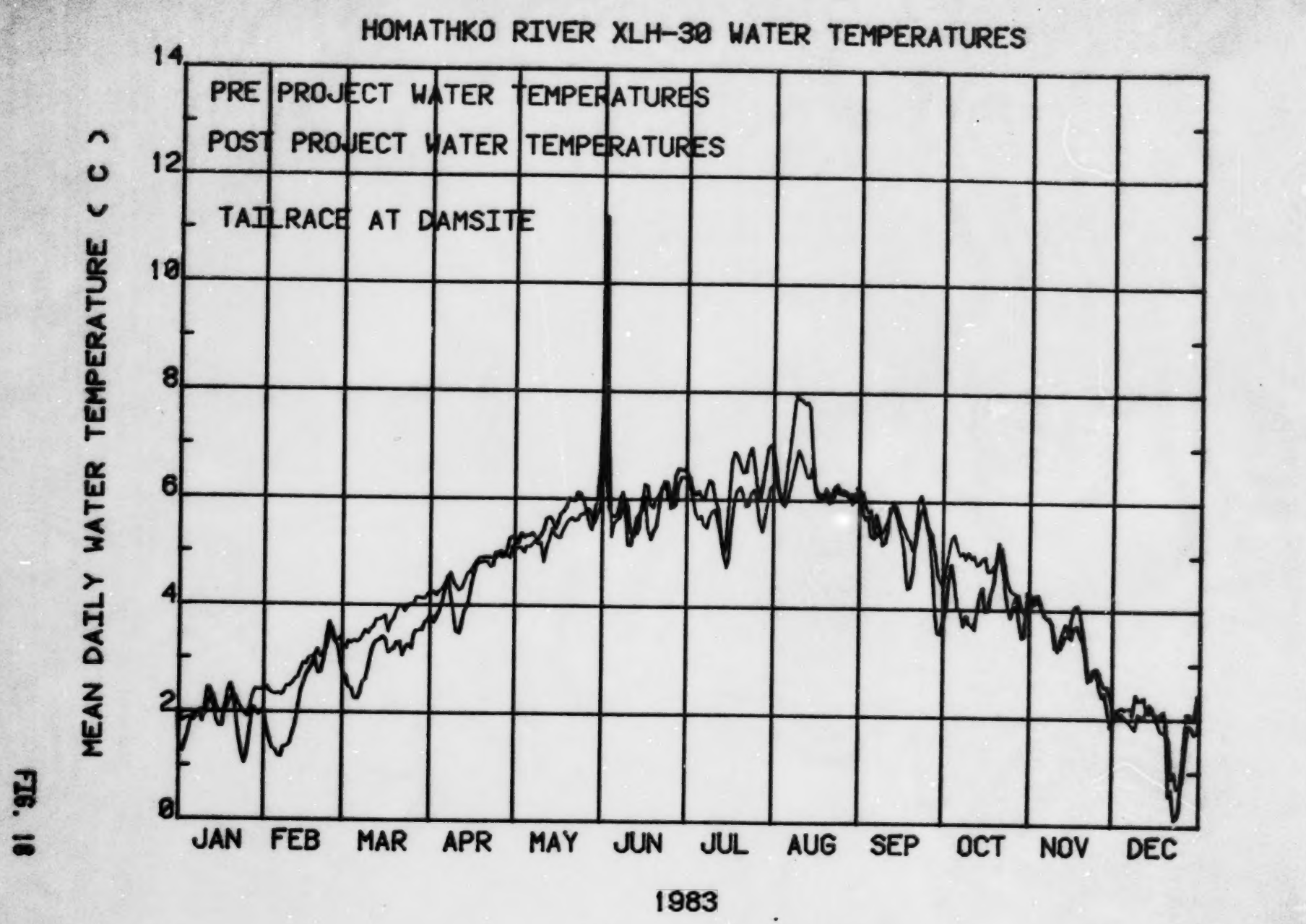

HOMATHKO RIVER XLH-30 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES
TAILRACE AT DAMSITE
MEAN DAILY WATER TEMPERATURE (C)
14
12
10
8
6
4
2
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1983

FIG. 18

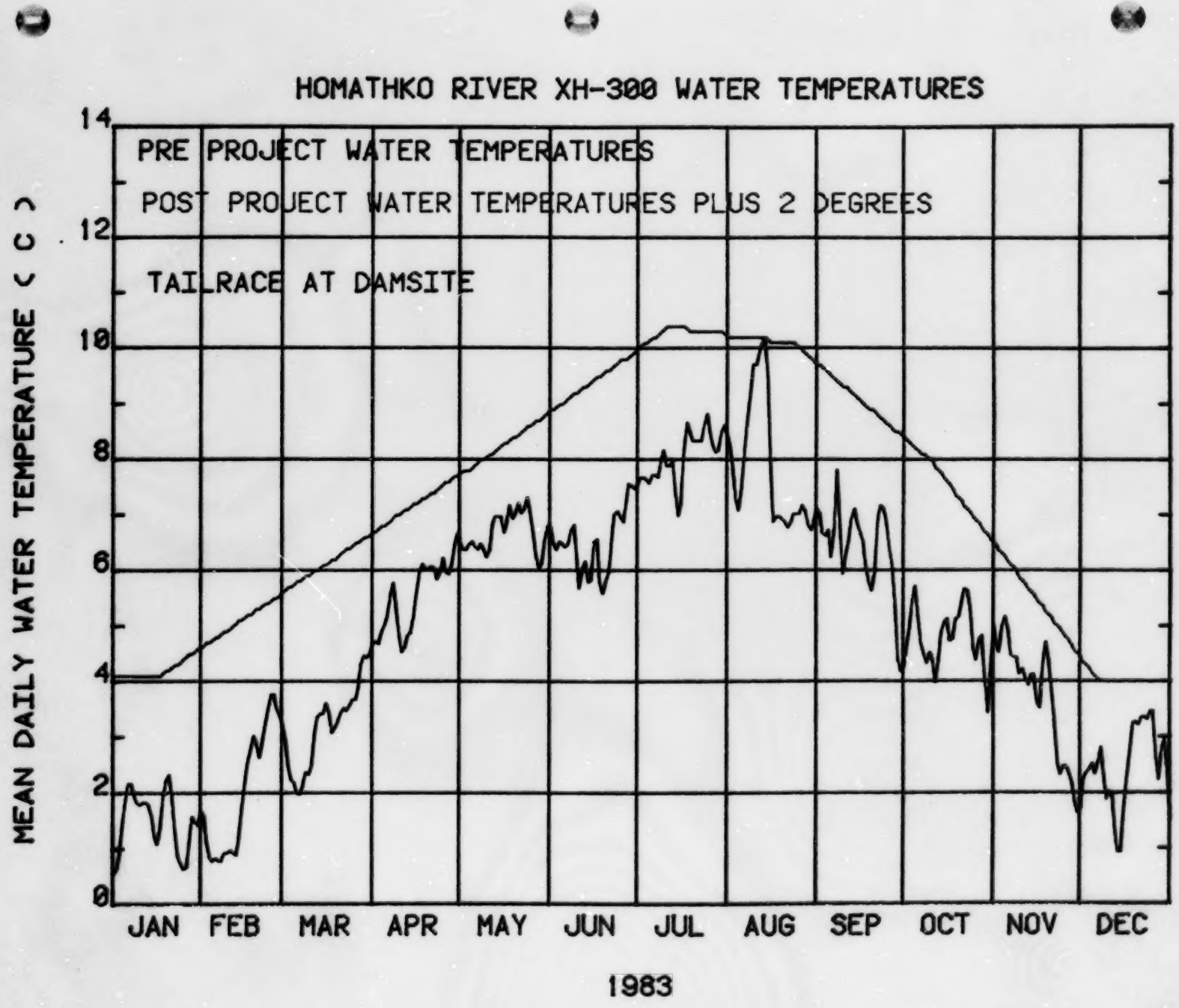

HOMATHKO RIVER XH-300 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES PLUS 2 DEGREES
TAILRACE AT DAMSITE
MEAN DAILY WATER TEMPERATURE (C)
14
12
10
8
6
4
2
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1983

FIG. 10

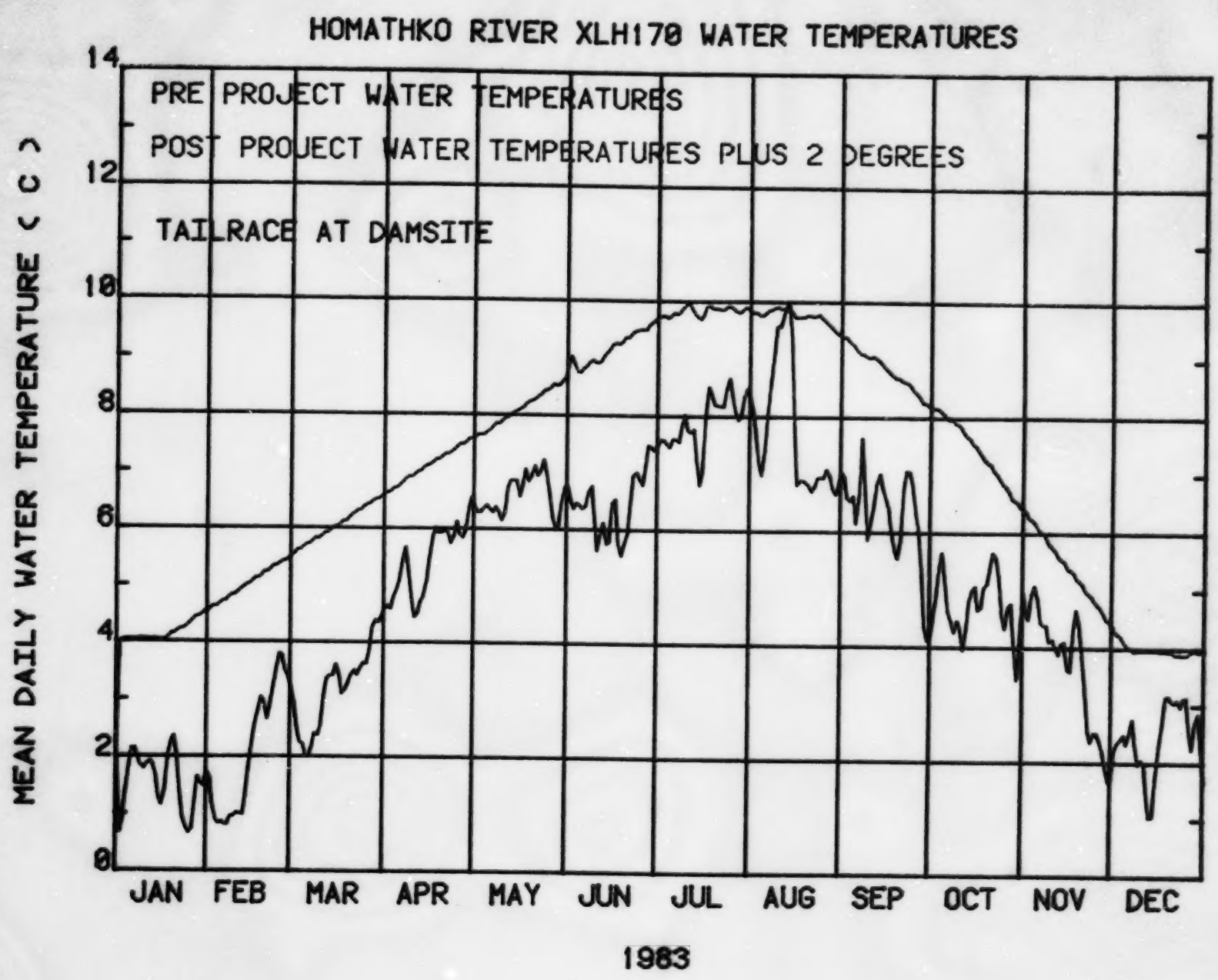

HOMATHKO RIVER XLH170 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES PLUS 2 DEGREES
TAILRACE AT DAMSITE
MEAN DAILY WATER TEMPERATURE (C)
14
12
10
8
6
4
2
0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
1983

FIG. 20

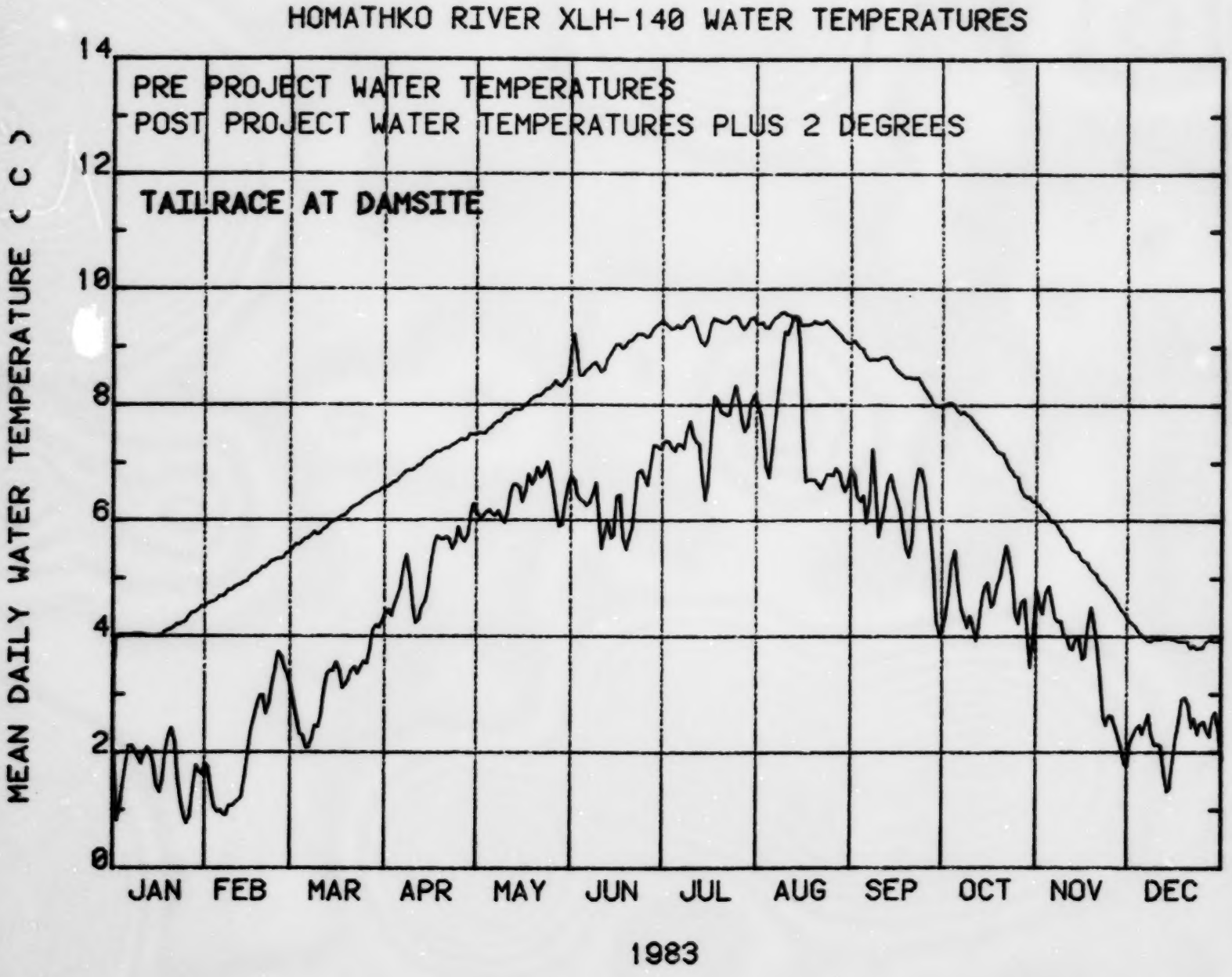

HOMATHKO RIVER XLH-140 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES PLUS 2 DEGREES
TAILRACE AT DAMSITE
MEAN DAILY WATER TEMPERATURE (C)
14
12
10
8
6
4
2
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1983

FIG. 21

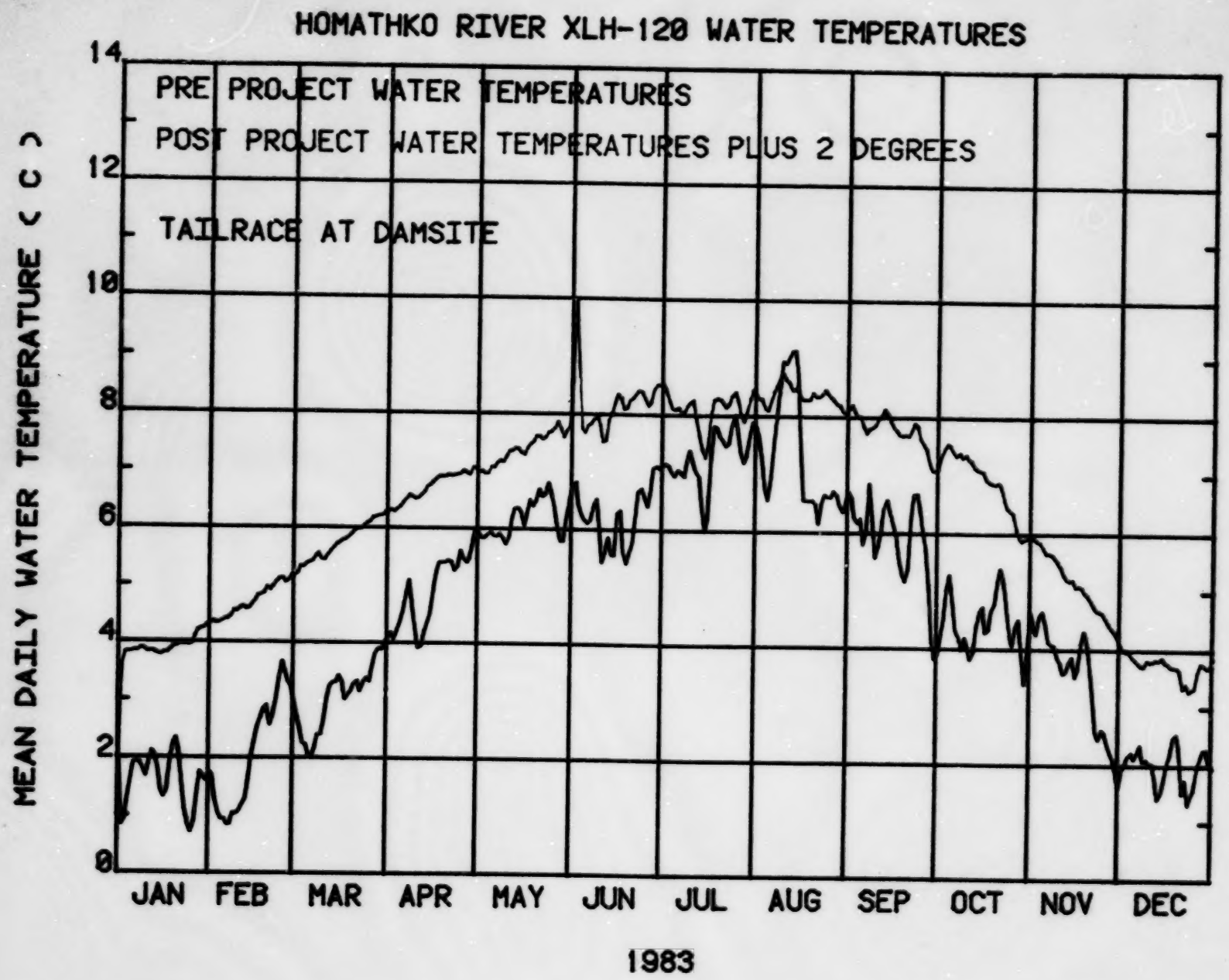

HOMATHKO RIVER XLH-120 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES PLUS 2 DEGREES
TAILRACE AT DAMSITE
MEAN DAILY WATER TEMPERATURE (C)
14
12
10
8
6
4
2
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1983

FIG. 22

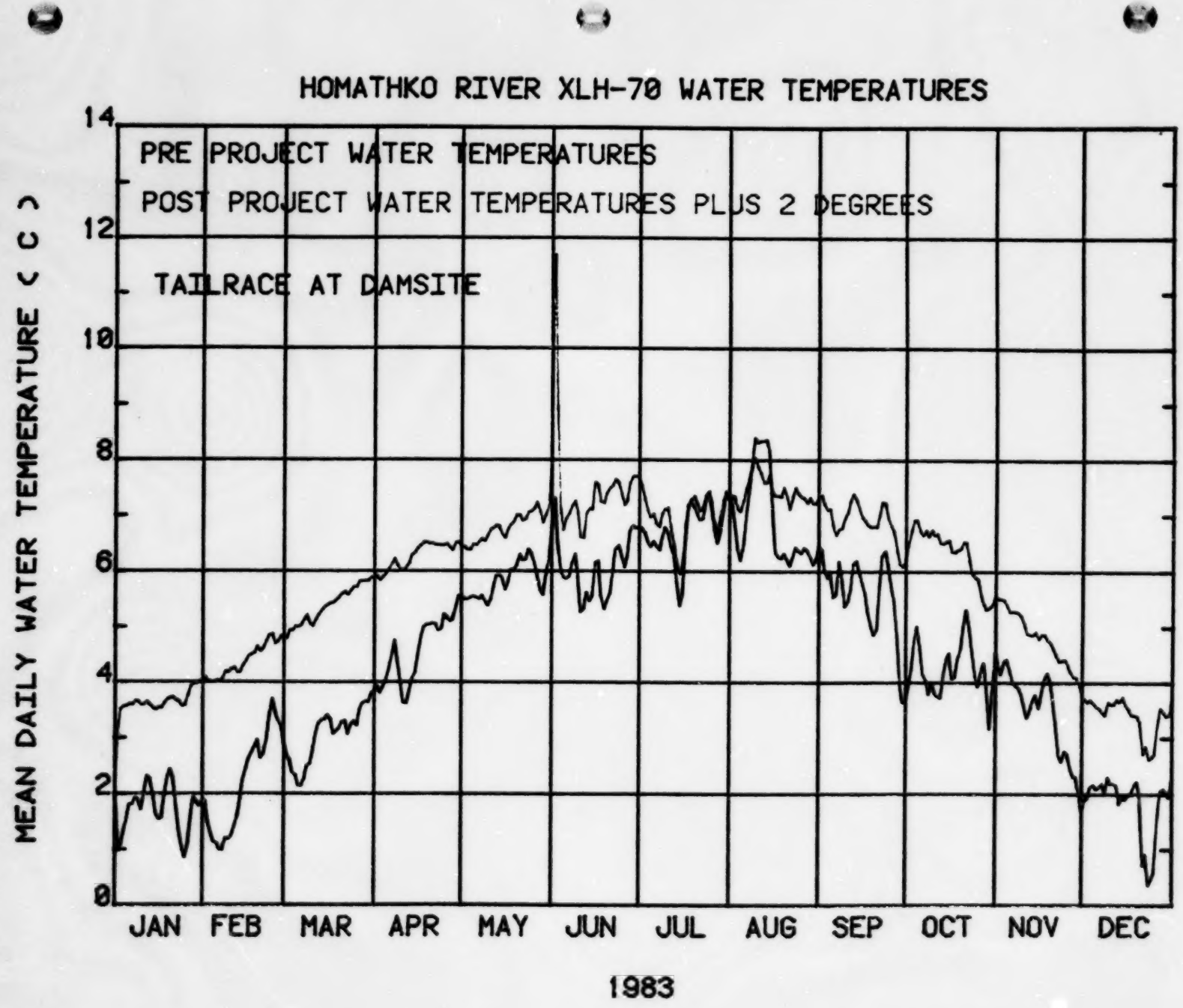

HOMATHKO RIVER XLH-70 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES PLUS 2 DEGREES
TAILRACE AT DAMSITE
MEAN DAILY WATER TEMPERATURE (C)
14
12
10
8
6
4
2
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1983

FIG. 23

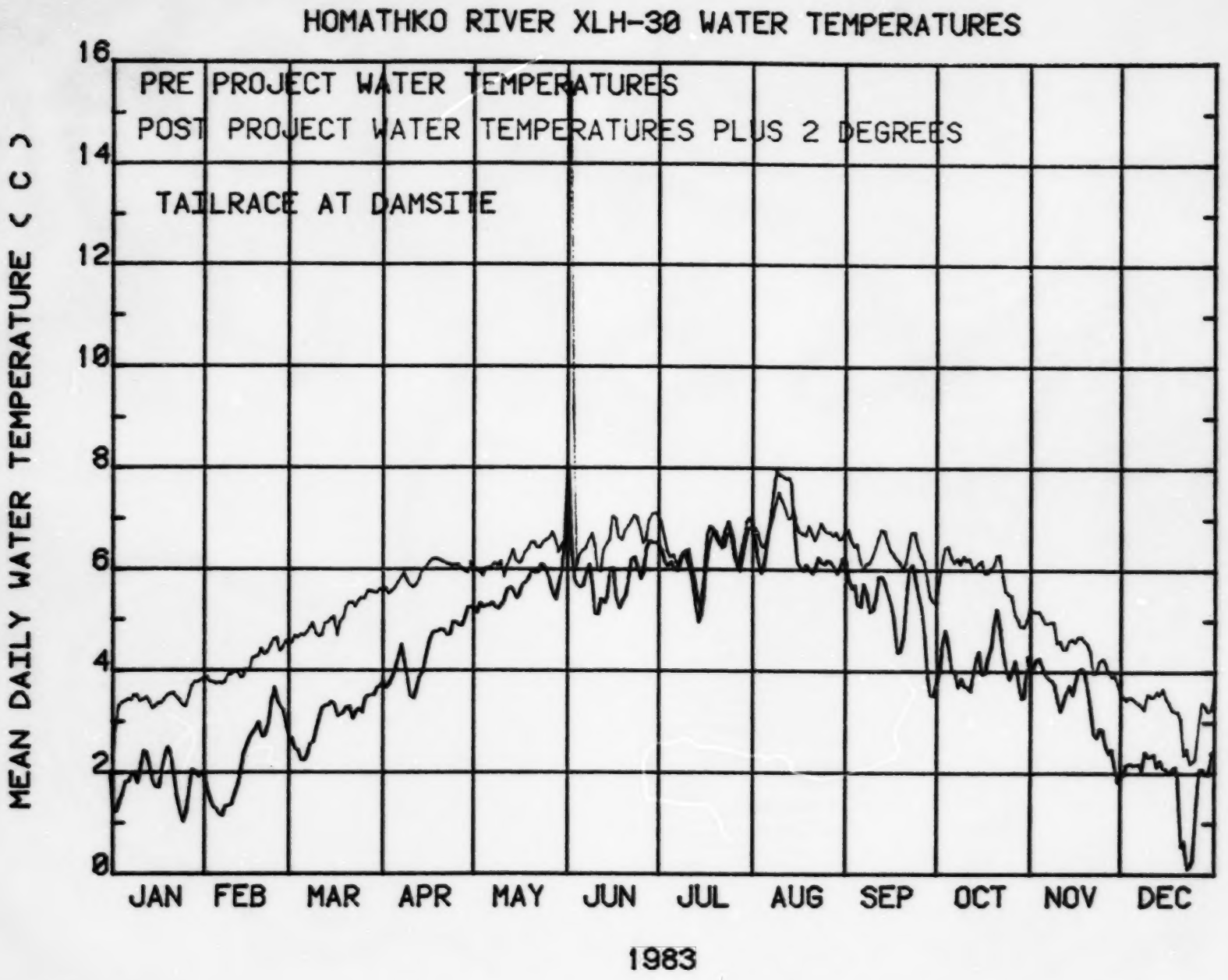

HOMATHKO RIVER XLH-30 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES PLUS 2 DEGREES
TAILRACE AT DAMSITE
MEAN DAILY WATER TEMPERATURE (C)
16
14
12
10
8
6
4
2
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1983

FIG. 24

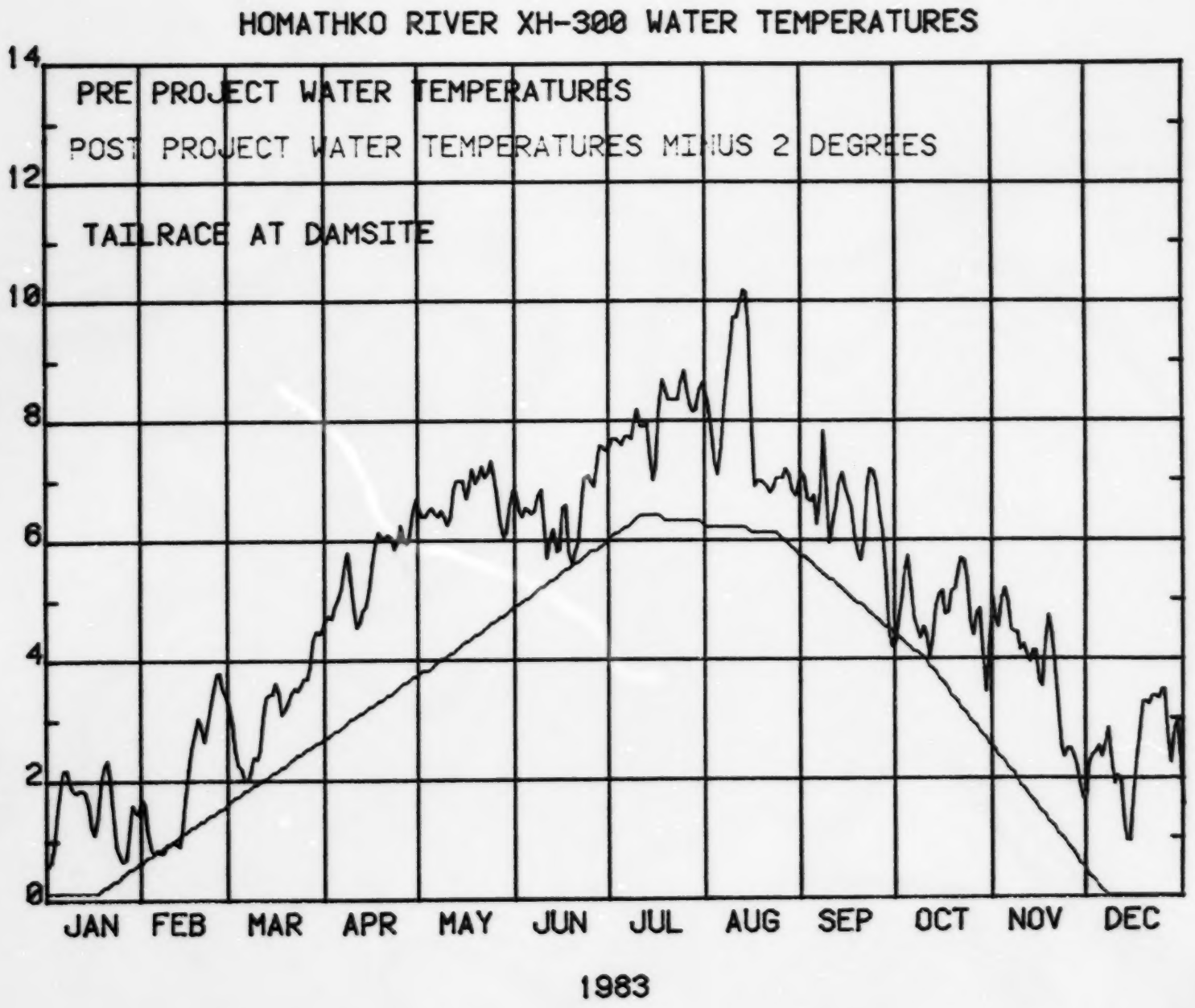

HOMATHKO RIVER XH-300 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES MINUS 2 DEGREES
TAILRACE AT DAMSITE
MEAN DAILY WATER TEMPERATURE (C)
14
12
10
8
6
4
2
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1983

FIG. 25

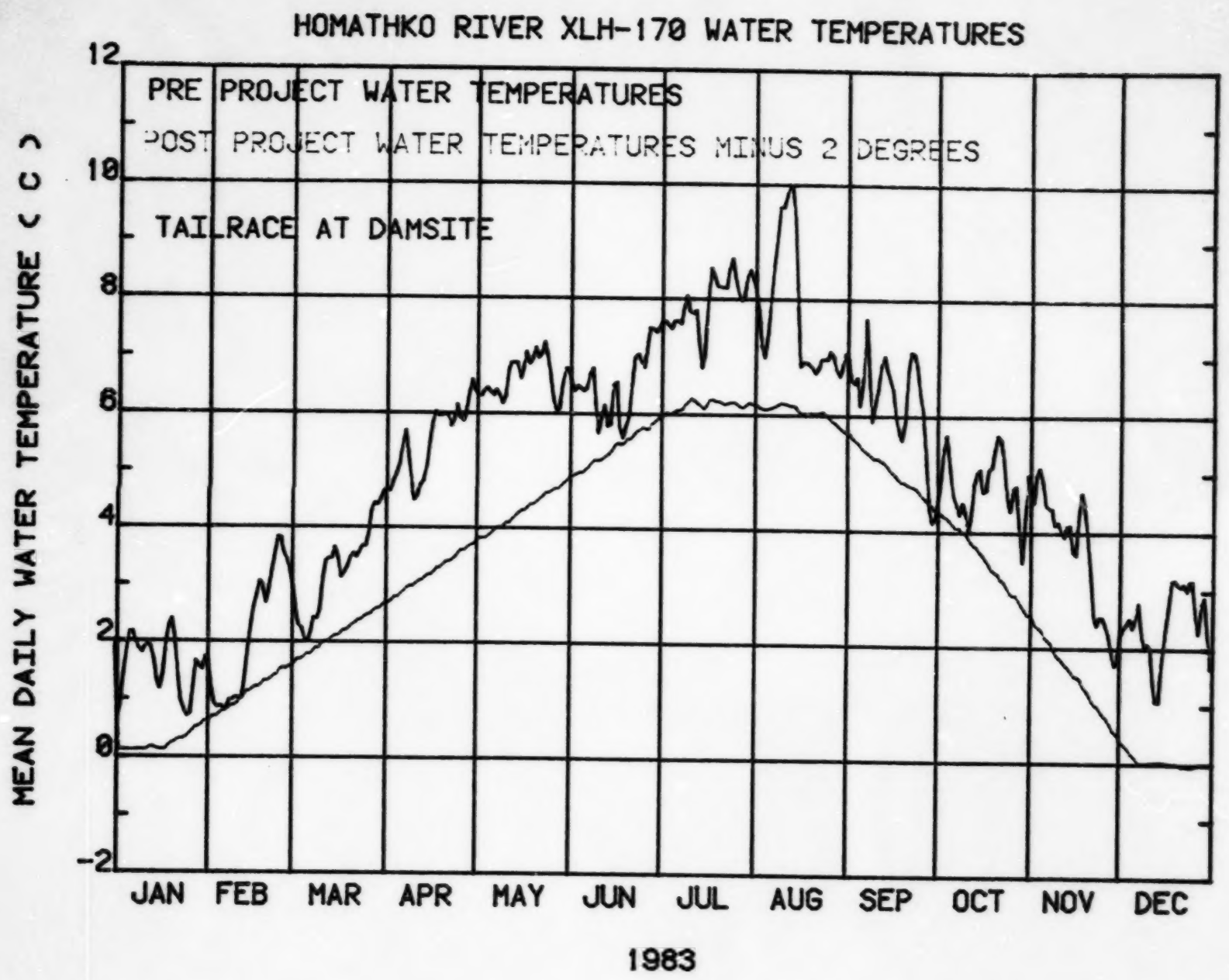

HOMATHKO RIVER XLH-170 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES MINUS 2 DEGREES
TAILRACE AT DAMSITE
MEAN DAILY WATER TEMPERATURE (C)
12
10
8
6
4
2
0
-2
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1983

FIG. 28

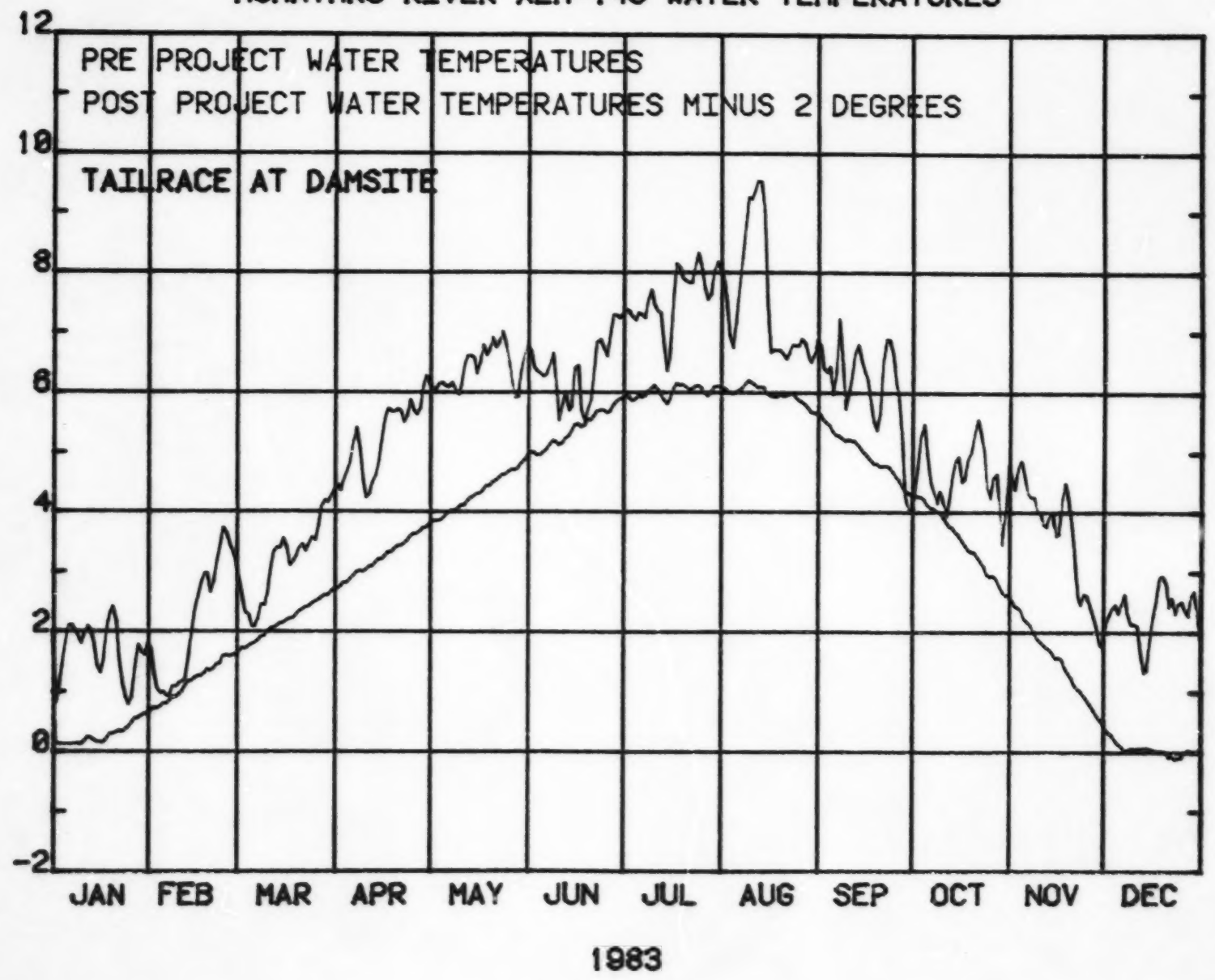

HOMATHKO RIVER XLH-140 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES MINUS 2 DEGREES
TAILRACE AT DAMSITE
MEAN DAILY WATER TEMPERATURE (C)
12
10
8
6
4
2
0
-2
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1983

FIG. 27

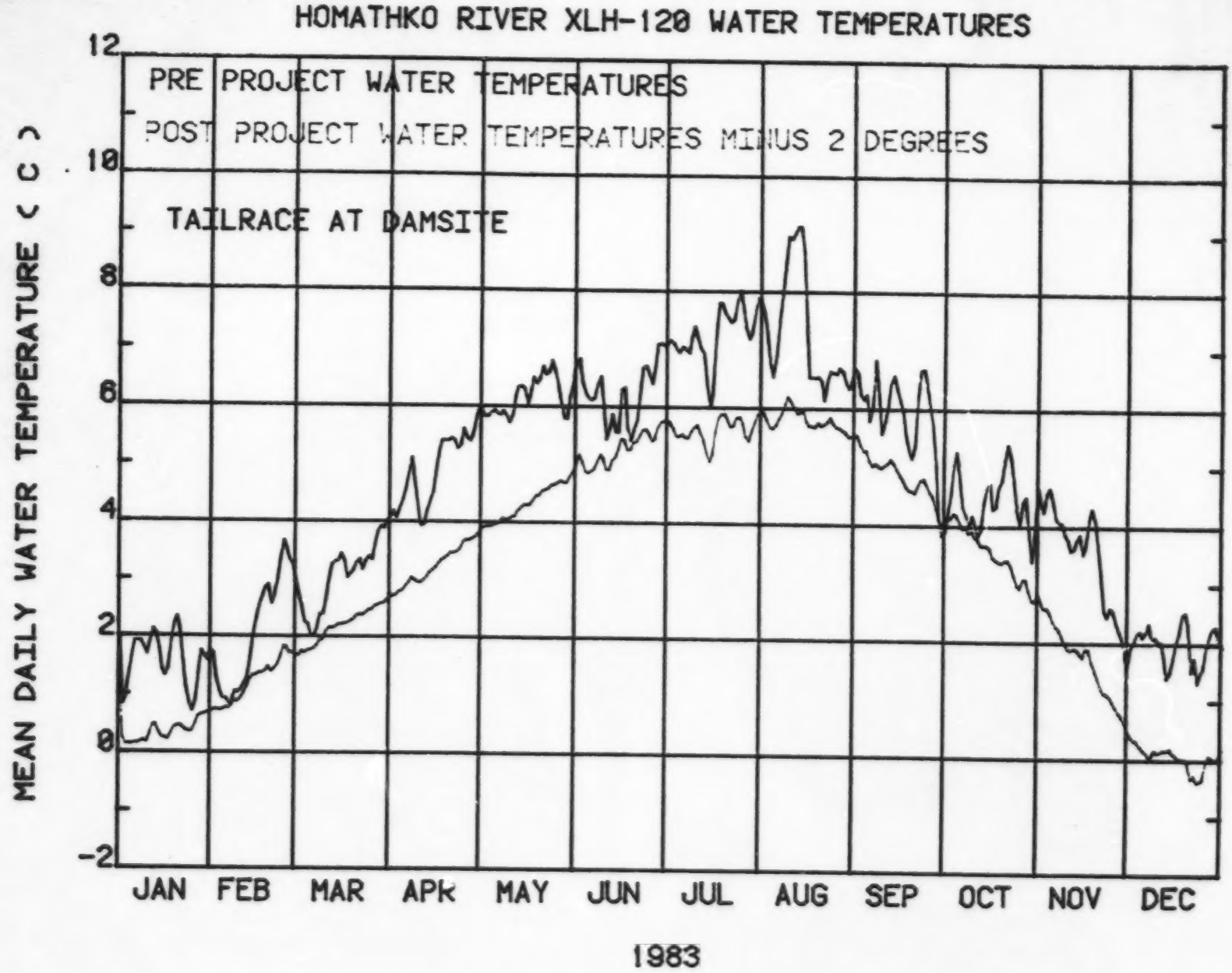

HOMATHKO RIVER XLH-120 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES MINUS 2 DEGREES
TAILRACE AT DAMSITE
MEAN DAILY WATER TEMPERATURE (C)
12
10
8
6
4
2
0
-2
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1983

FIG. 28

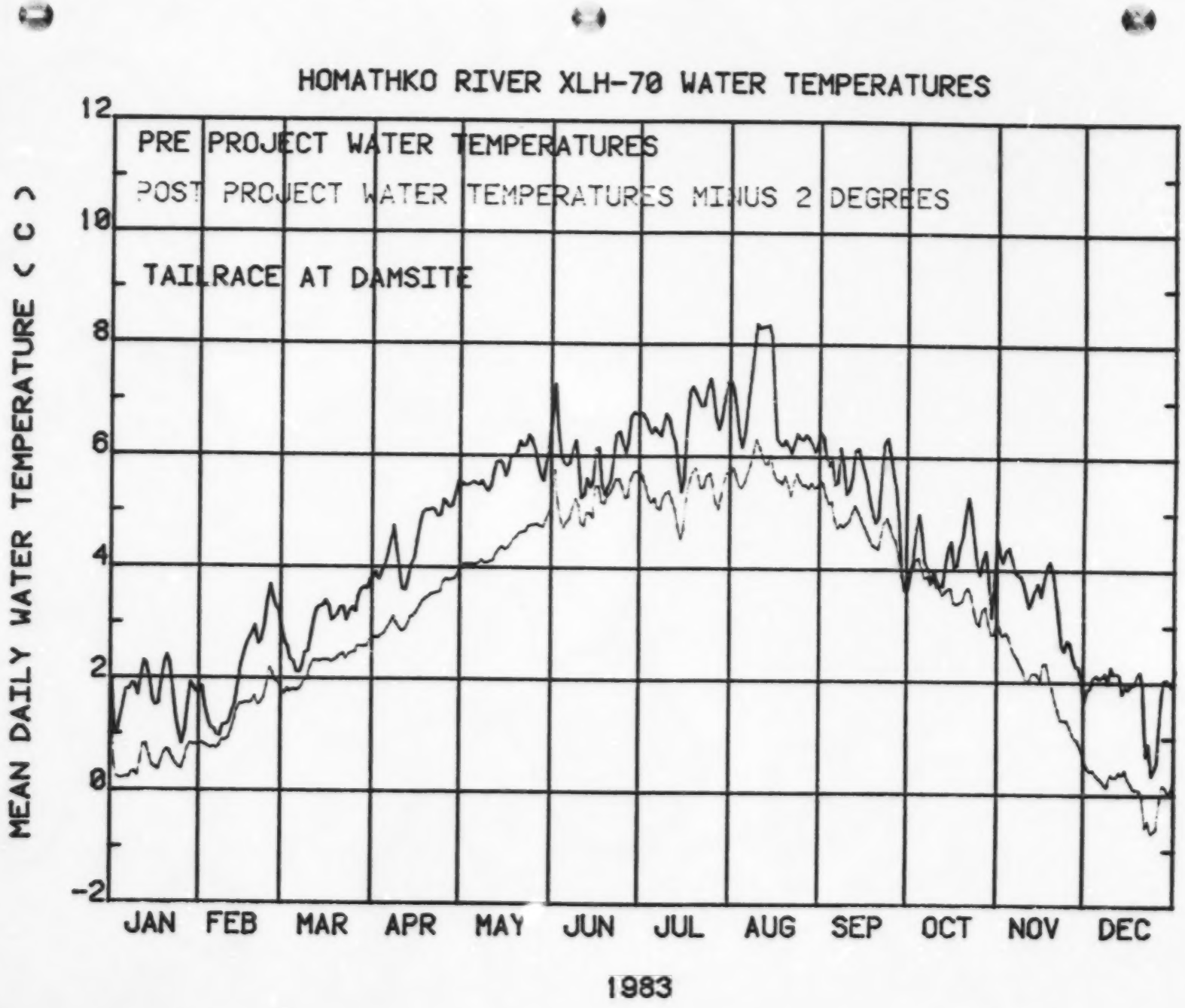

HOMATHKO RIVER XLH-70 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES MINUS 2 DEGREES
TAILRACE AT DAMSITE
MEAN DAILY WATER TEMPERATURE (C)
12
10
8
6
4
2
0
-2
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1983

FIG. 28

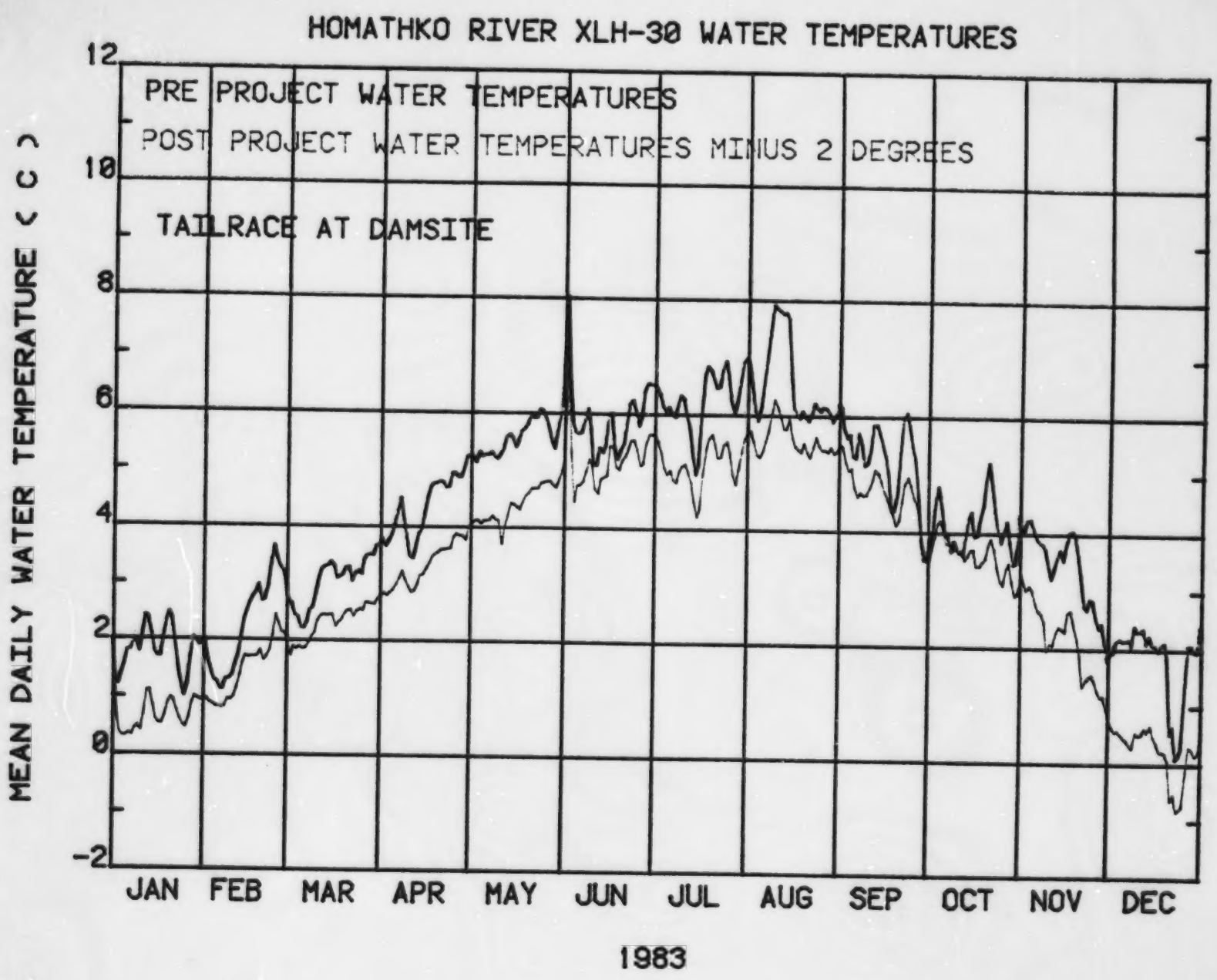
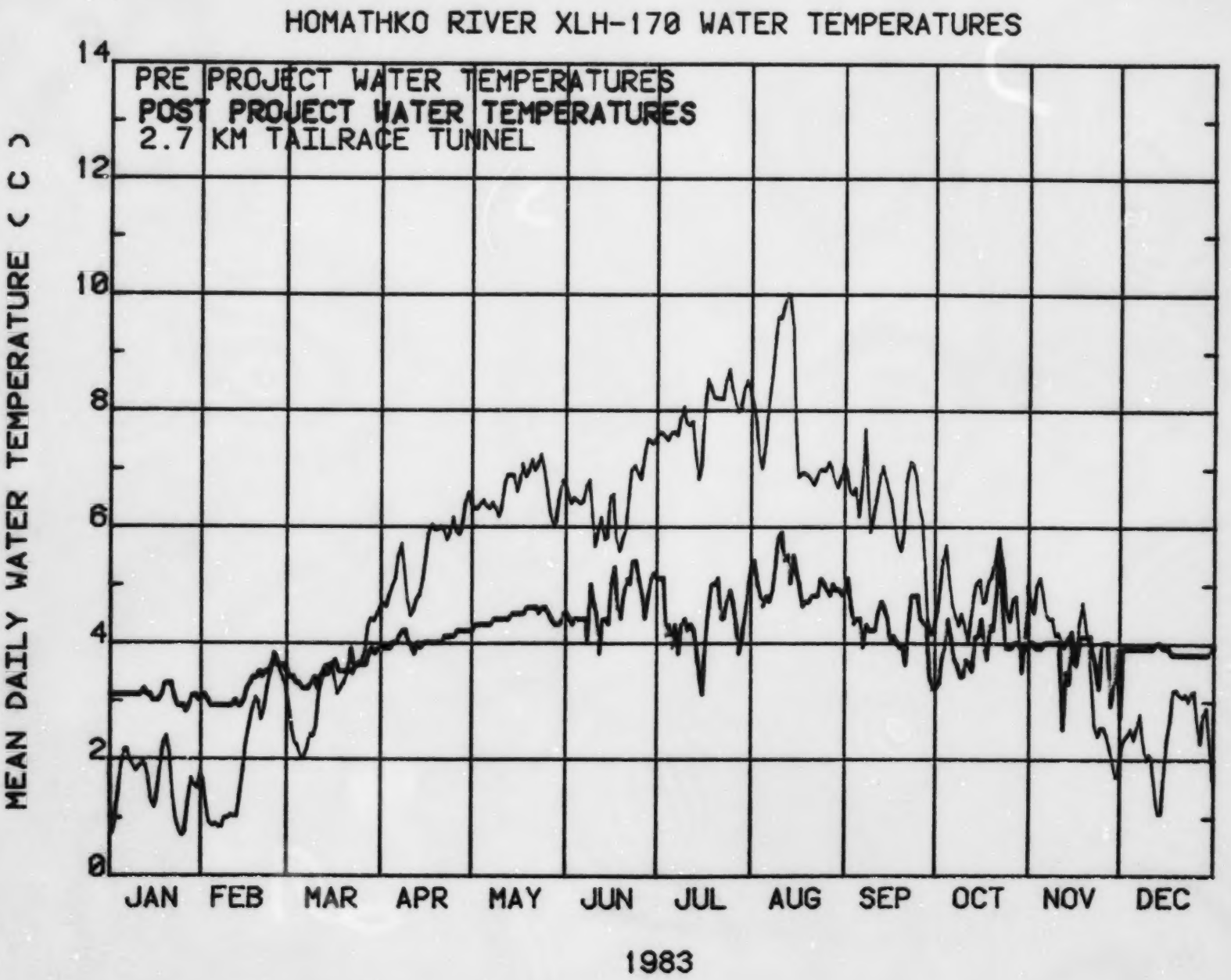

HOMATHKO RIVER XLH-30 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES MINUS 2 DEGREES
TAILRACE AT DAMSITE
MEAN DAILY WATER TEMPERATURE (C)
12
10
8
6
4
2
0
-2
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1983

FIG. 30


HOMATHKO RIVER XLH-170 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES
2.7 KM TAILRACE TUNNEL
MEAN DAILY WATER TEMPERATURE (C)
14
12
10
8
6
4
2
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JAN
FEB
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MAY
JUN
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SEP
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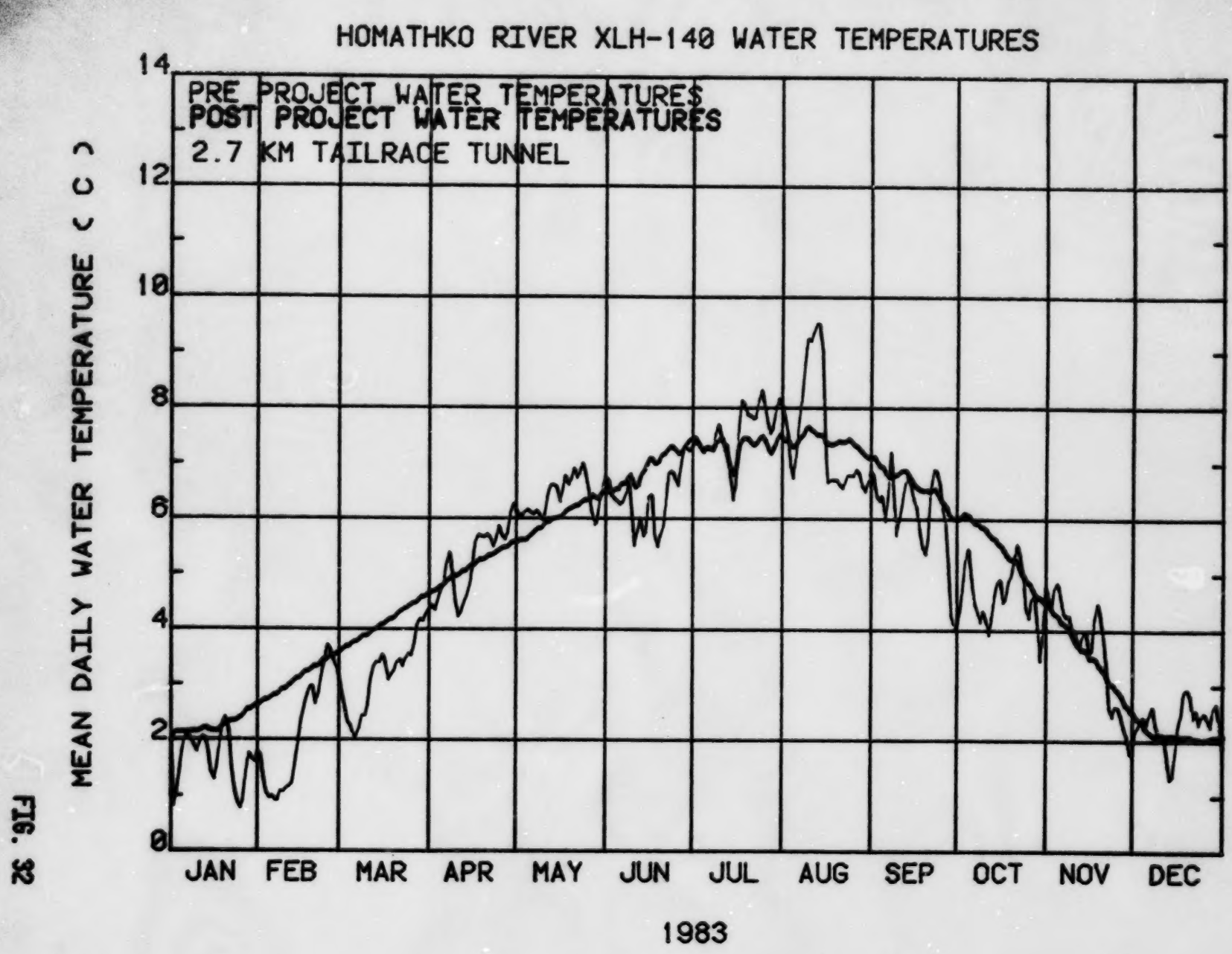
DEC
1983

FIG. 31


HOMATHKO RIVER XLH-140 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES
2.7 KM TAILRACE TUNNEL
MEAN DAILY WATER TEMPERATURE (C)
14
12
10
8
6
4
2
0
JAN
FEB
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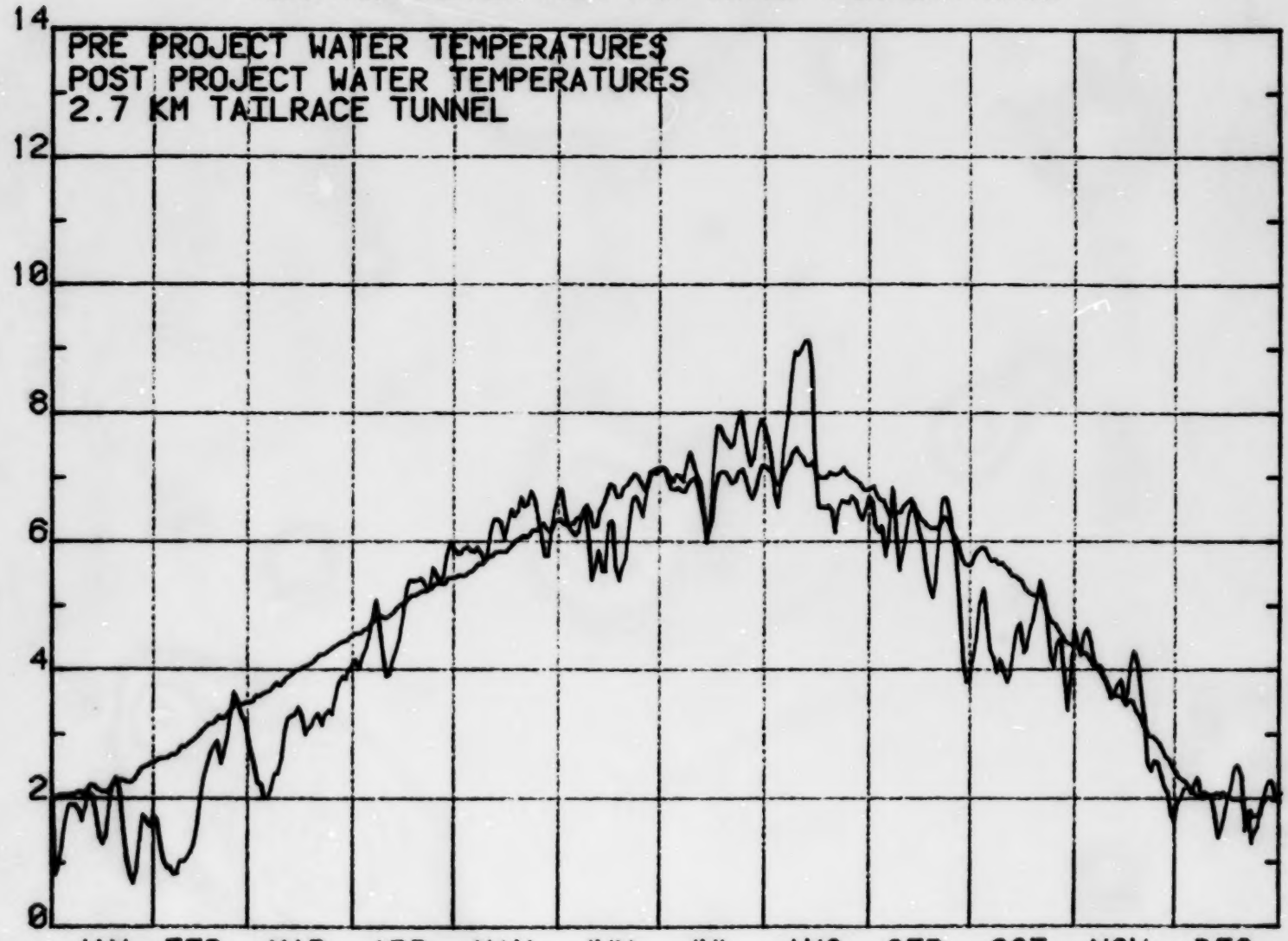
1983

FIG. 32


HOMATHKO RIVER XLH-120 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES
2.7 KM TAILRACE TUNNEL
MEAN DAILY WATER TEMPERATURE (C)
14
12
10
8
6
4
2
0
JAN
FEB
MAR
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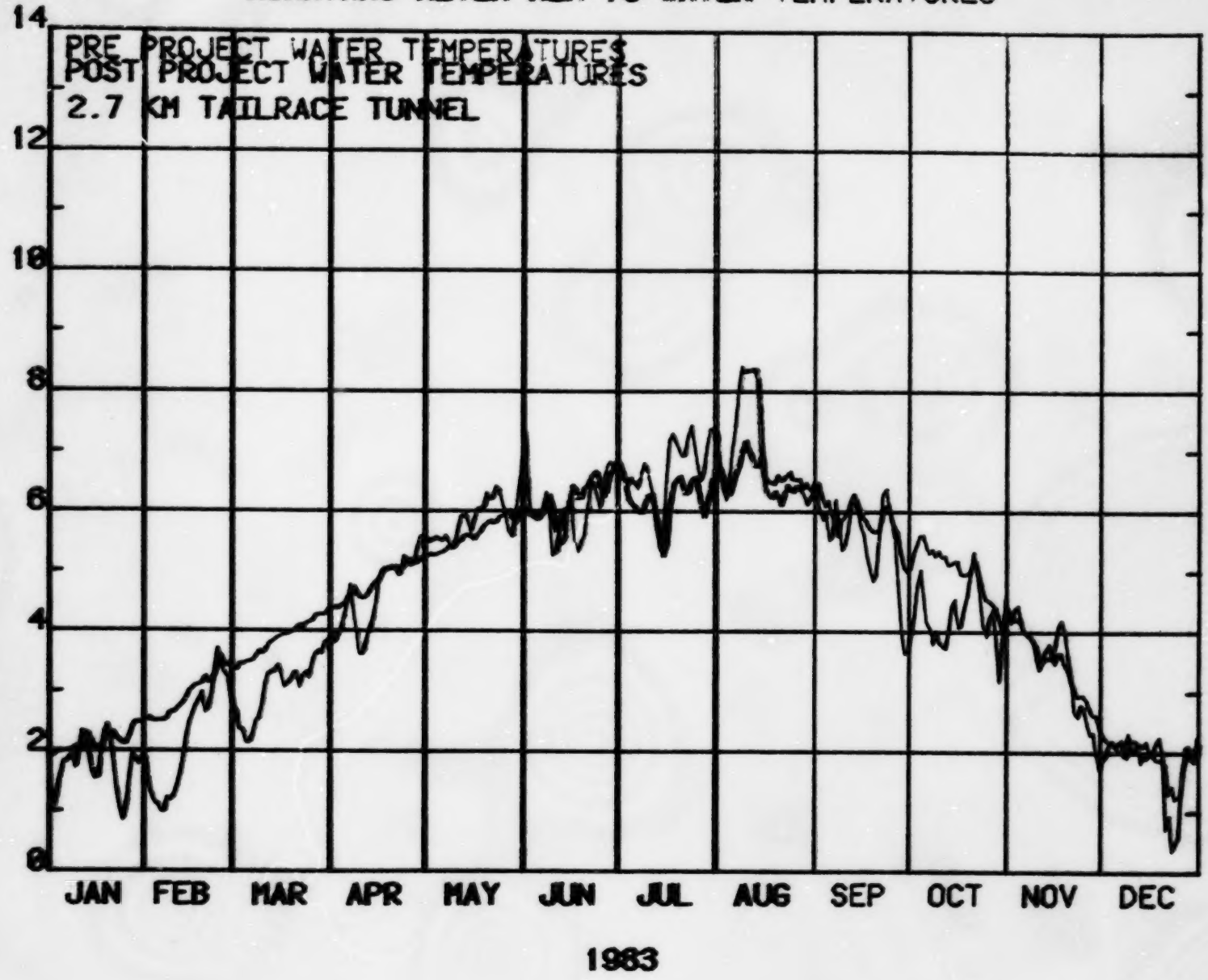
1983

FIG. 33


HOMATHKO RIVER XLH-70 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES
2.7 KM TAILRACE TUNNEL
MEAN DAILY WATER TEMPERATURE (C)
14
12
10
8
6
4
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JAN
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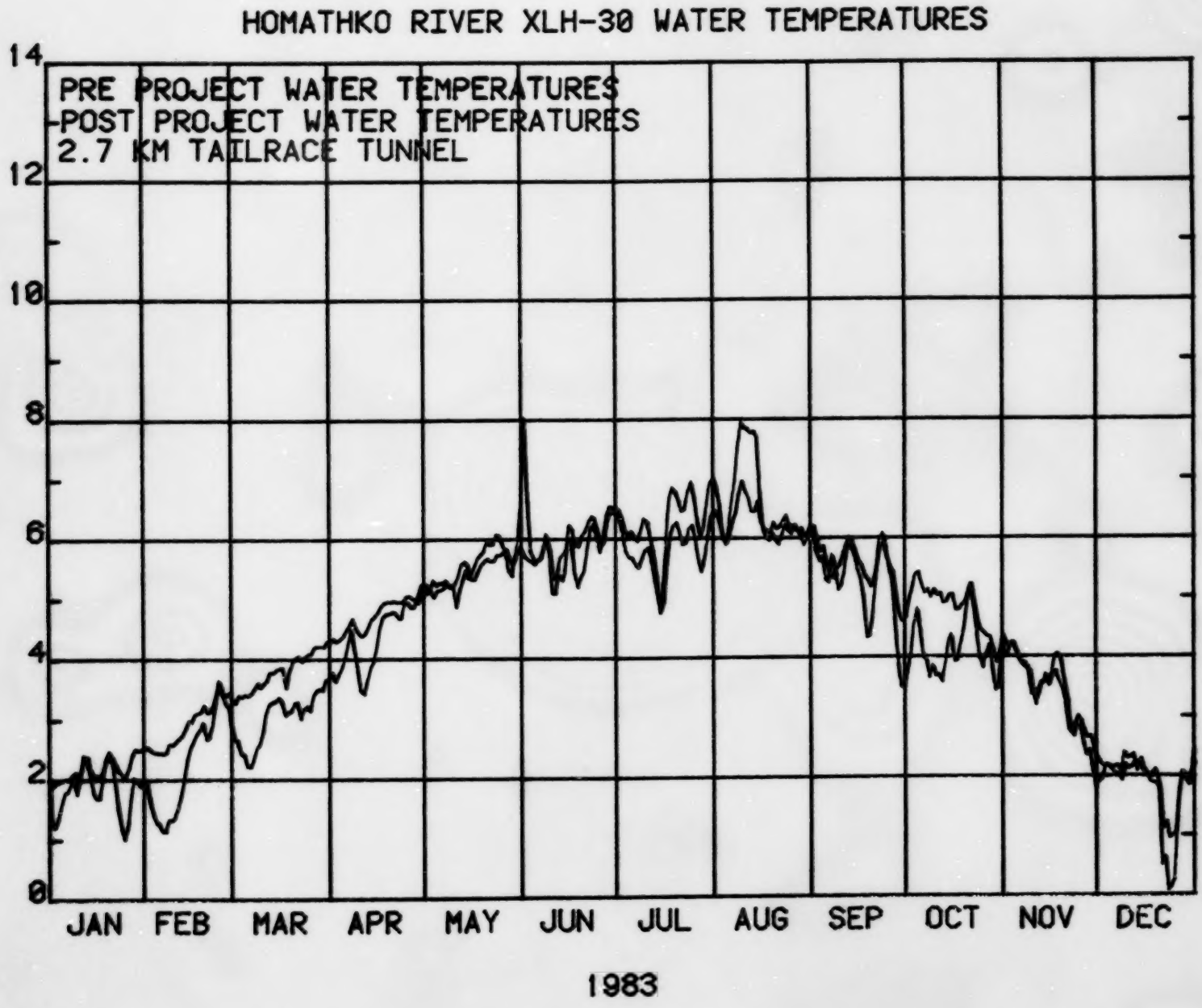
FIG. 34


HOMATHKO RIVER XLH-30 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES
2.7 KM TAILRACE TUNNEL
MEAN DAILY WATER TEMPERATURE (C)
14
12
10
8
6
4
2
0
JAN
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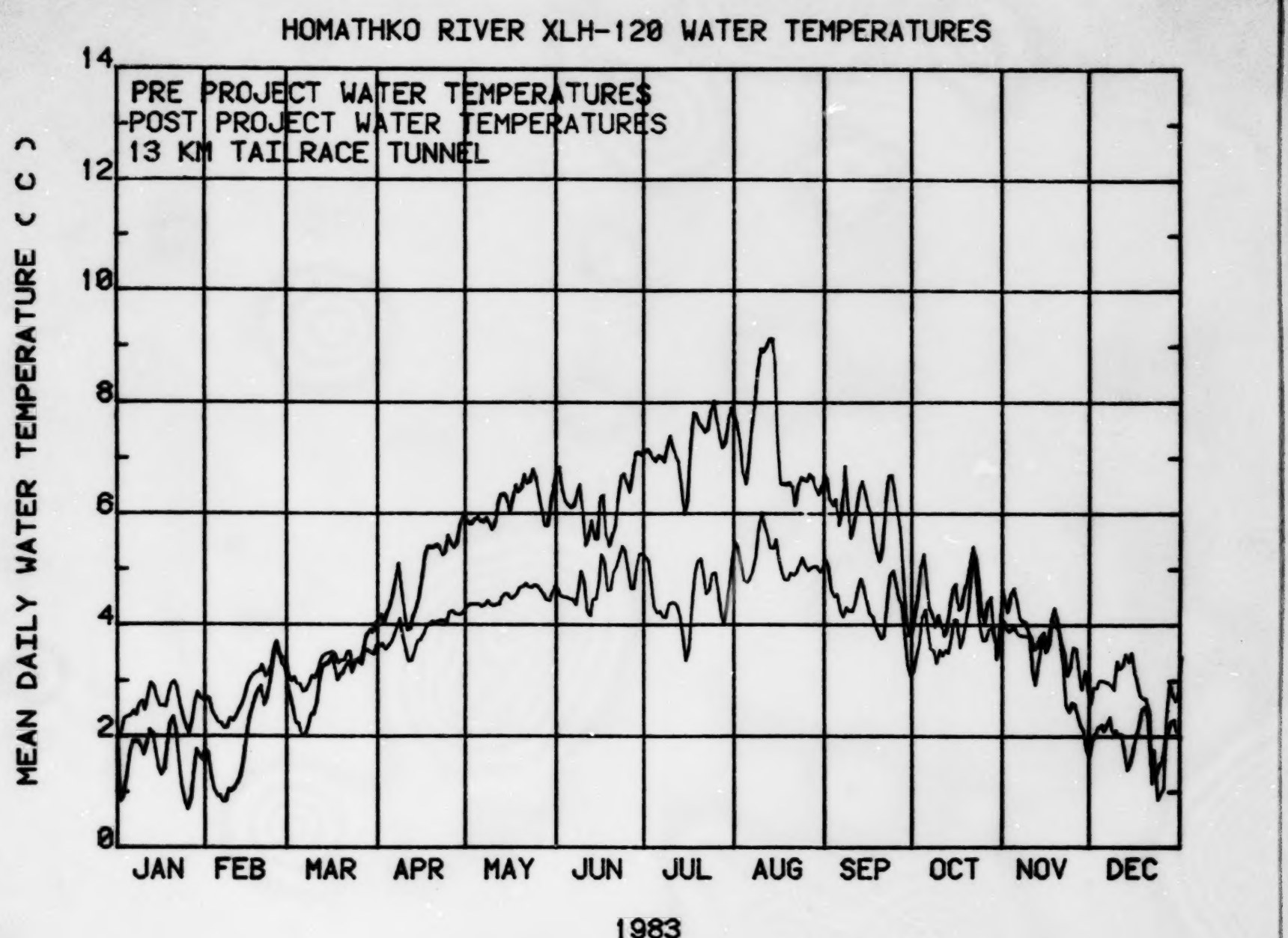
OCT
NOV
DEC
1983

FIG. 36


HOMATHKO RIVER XLH-120 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES
13 KM TAILRACE TUNNEL
MEAN DAILY WATER TEMPERATURE (C)
14
12
10
8
6
4
2
0
JAN
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MAY
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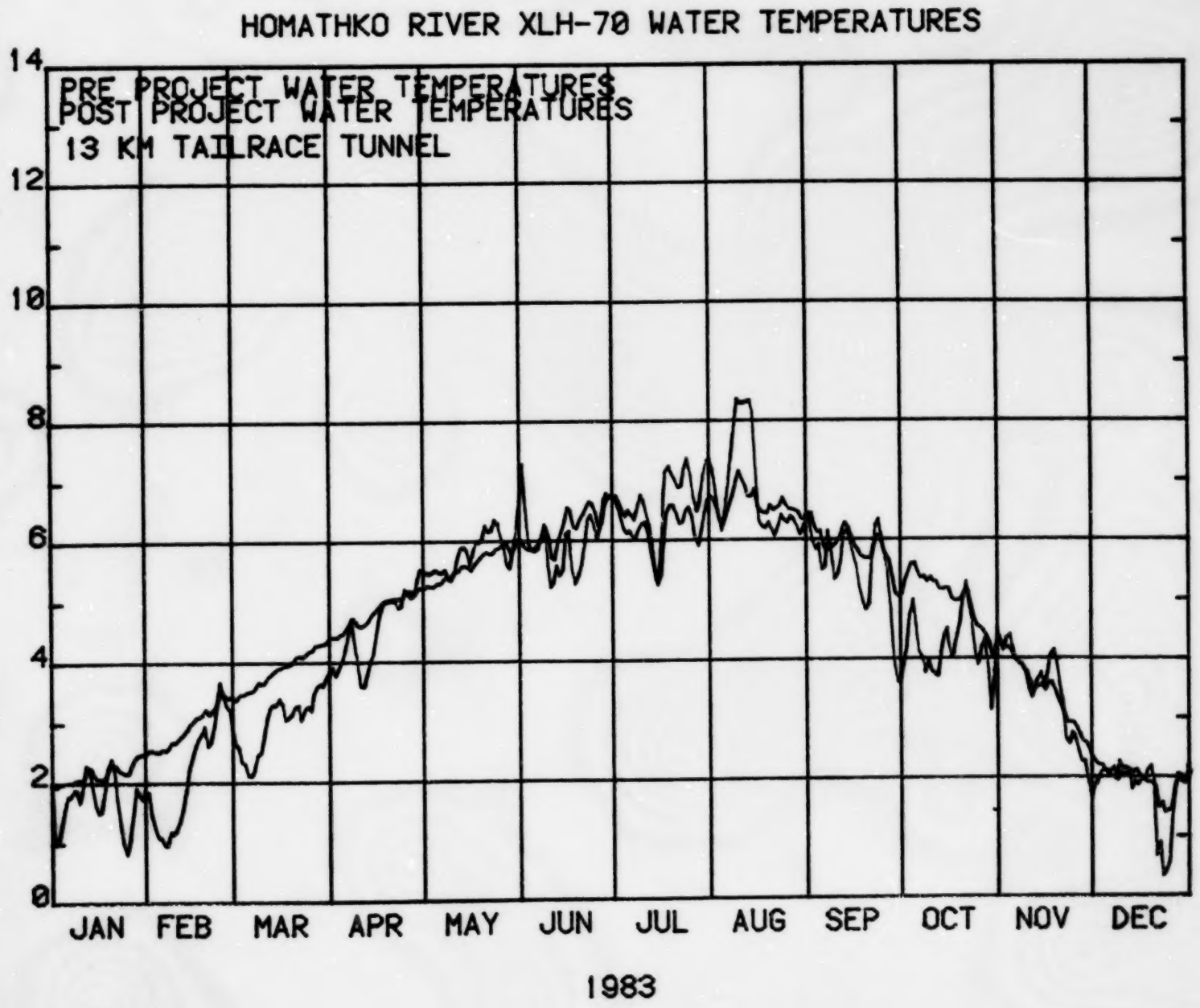
DEC
1983

FIG. 36


HOMATHKO RIVER XLH-70 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES
13 KM TAILRACE TUNNEL
MEAN DAILY WATER TEMPERATURE (C)
14
12
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8
6
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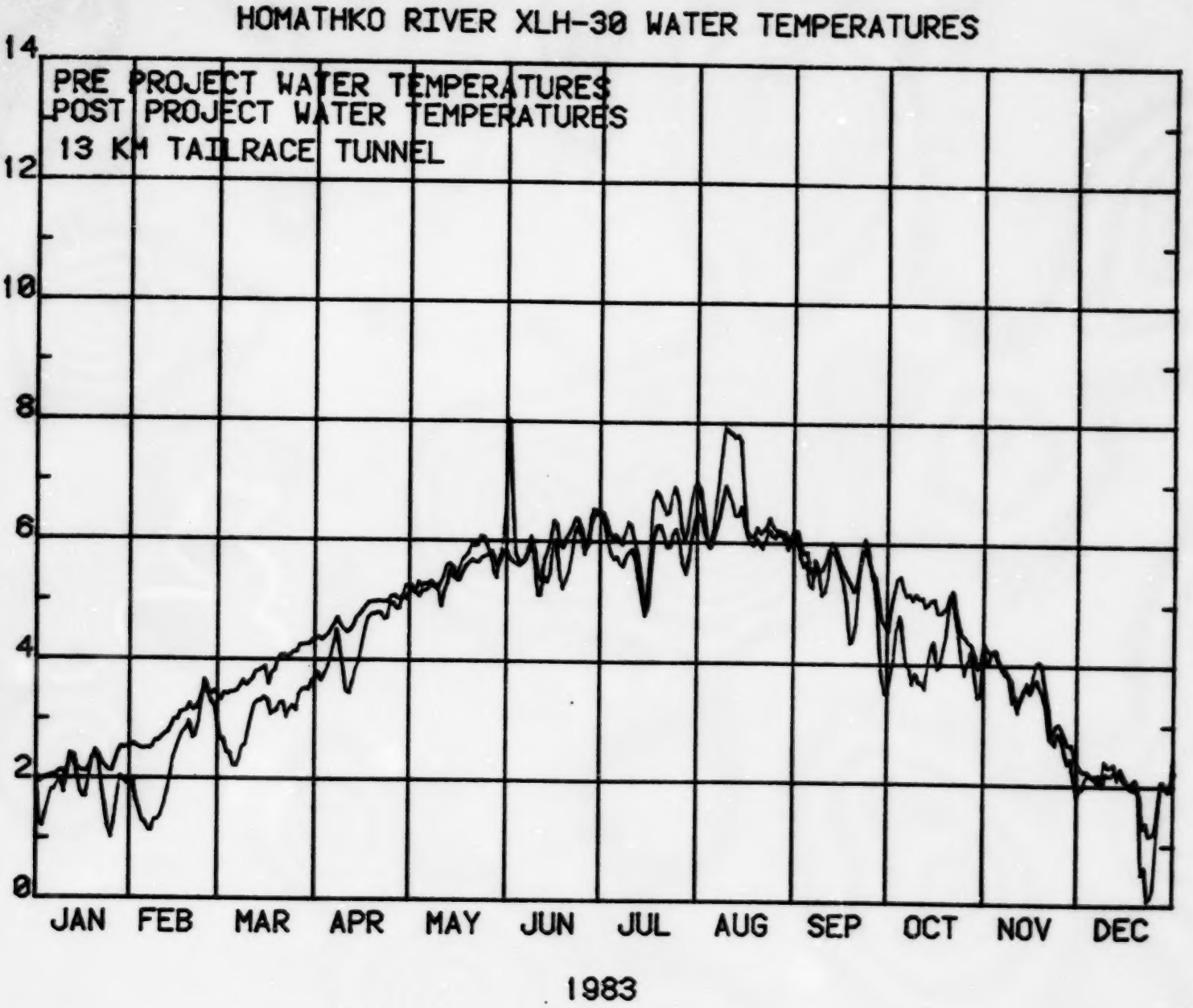
FIG. 37


HOMATHKO RIVER XLH-30 WATER TEMPERATURES
PRE PROJECT WATER TEMPERATURES
POST PROJECT WATER TEMPERATURES
13 KM TAILRACE TUNNEL
MEAN DAILY WATER TEMPERATURE (C)
14
12
10
8
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4
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0
JAN
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FIG. 38

CCBS MICRO GRAPH

G -142

1 YEAR BY DAYS X 250 DIVNS.
CALENDER YEAR

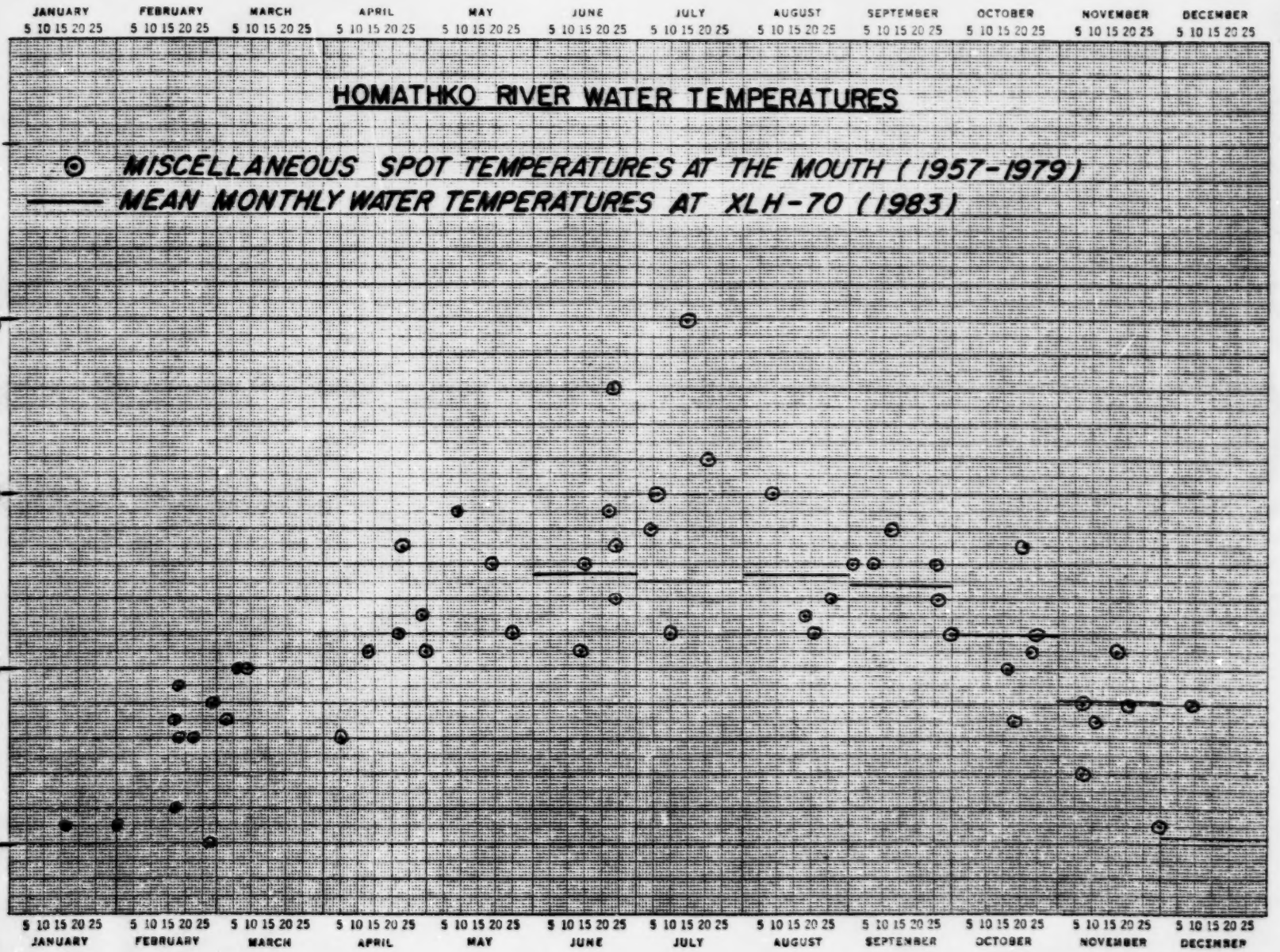
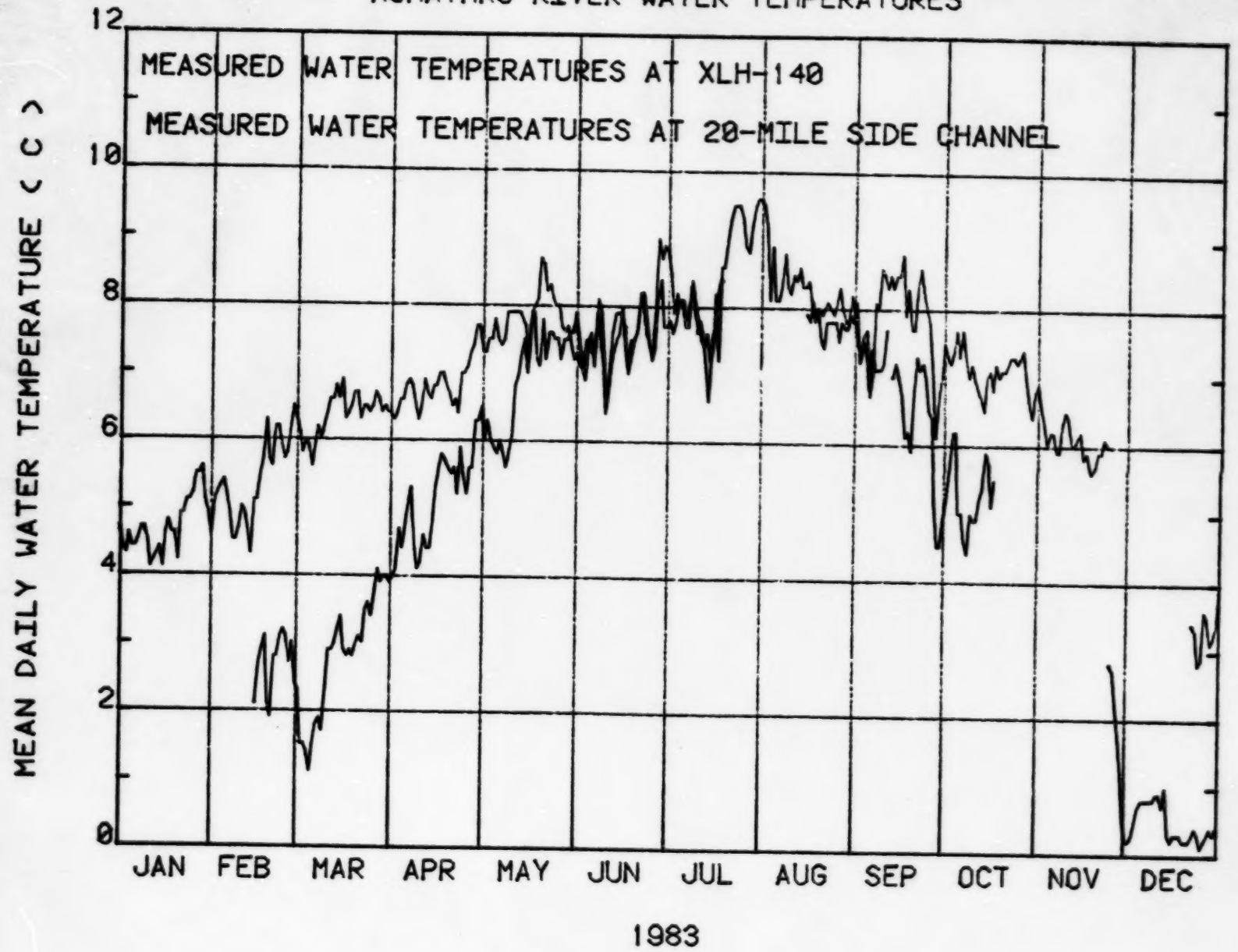


FIG 39


HOMATHKO RIVER WATER TEMPERATURES
MEASURED WATER TEMPERATURES AT XLH-140
MEASURED WATER TEMPERATURES AT 20-MILE SIDE CHANNEL
MEAN DAILY WATER TEMPERATURE (C)
12
10
8
6
4
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JAN
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1983

FIG. 49

ATTACHMENT 1

TERMS OF REFERENCE

ENVIRONMENTAL HYDROLOGY - (3) THERMAL REGIME

PRELIMINARY

HOMATHKO DEVELOPMENT (GENERATION)

Terms of Reference*

Environmental Hydrology - (3) Thermal Regime

1.0 INTRODUCTION

The proposed regulation of Homathko River would modify the hydrologic regime of the lower Homathko, including the thermal regime. Modification of the thermal regime by reservoir impoundment and flow regulation could lead to possible impacts on the anadromous fish species which utilize the lower Homathko mainstem, backchannels and tributaries. Water temperature has been documented to be an important factor in the incubation rate, growth rate and survival of juvenile salmonids (Alderdice and Velsen, 1978). Therefore, it is important to determine the nature of the natural thermal regime of the lower Homathko and provide a preliminary estimate of the range of changes to be expected under regulation.

To allow sufficient time to complete 1983 environmental assessments and to plan 1984/85 environmental studies, this report should be completed by 31 March 1984. An interim report is required by 31 December 1983, giving preliminary results for study items (4.0(a)(4) and 4.0(b)(2). It is assumed that flow data until September 1983 will be available, and results for cross sections XLH 30, XLH 120 and XLH 180 only are required.

Note: Beside each item one of the following symbols has been placed to indicate the degree of completion as some items were not completed due to the program of budget restraint:

* - Item completed
U - Item uncompleted
P - Item partially completed

2.0 OBJECTIVES

The objectives of this feasibility study are to document the existing thermal regime of the lower Homathko River and to simulate the thermal regime in order to examine the effects of flow regulation. A network of 10 continuously recording thermographs are proposed to be installed on the Homathko River and its tributaries, to supplement the recorders installed at the five WSC stations.

Due to the possible importance of the thermal regime of the lower Homathko River to the fisheries resource, the natural and regulated temperatures should be examined in detail. It is assumed that a river simulation model will be run this year to determine the range of changes to be expected under regulation. The sensitivity of the salmonid species to these temperatures will be addressed prior to designing the 1984/85 data collection program.

3.0 INVENTORY

1.* Continuously recording thermographs should be installed and maintained at the following eight locations:

Homathko River at XLH 70
Homathko River below XLH 120, backchannel
Homathko River at XLH 140
Homathko River at XH 300
Klattasine Creek
Brew Creek
Scar Creek
Jewakwa River

The instruments need servicing once per month (7), and once per week (3). Calibration temperatures should be measured whenever

recorder charts are changed or the instruments checked. Additional spot temperature measurements (e.g. opposite bank from recorder up and downstream, other tributaries, secondary channel vs mainstem) should be made whenever possible to document the spatial variability of temperatures.

2.* Conduct a temperature profile of the lower Homathko River, starting at Waddington Canyon (XLH 190), and taking a mid-channel temperature at each cross section and at the following tributary confluences - Klattasine, Scar, Whitemantle, Brew, Jewakwa and Heakamie. At each tributary, temperatures should be taken R & L bank upstream of the confluence, tributary, R & L bank immediately below confluence, R & L bank 0.25 km, 0.5 km, 0.75 m and 1 km below confluence. This survey should be repeated three times - July, August and September.

4.0 ASSESSMENT

(a) Natural Regime

1.* For the five WSC stations with continuously recording thermographs, and the eight recording thermographs, prepare the following:

Plots of mean, maximum and minimum daily temperatures for the period of record. Data should be presented in both graphical and tabular format.

2.* All spot temperature measurements (B.C. Hydro, Environmental Sciences Ltd. 1982/83, WSC) should be presented.

3.* Review the available data base of Homathko hydrological, meteorological and water temperature data and the available

methodologies for river temperature modelling. The literature review should include at least Theurer and Voos (1983), Water Resources Engineers (1970), HGPD (1981, 1982), Morse (1970, 1972, 1978) and the studies currently being conducted by HGPD on the Stikine and Liard rivers. The most suitable model for the requirements and characteristics of the Homathko River should be recommended. This review and recommendation should be prepared as an interim report, for discussion with ESS and possibly external reviewers prior to operationalizing a model.

4.* Simulate the natural water temperature regime of the lower Homathko River for 1983. Simulated mean daily values should be presented for the lower Homathko cross sections XLH 20, 30, 40, 70, 110, 120, 140, 155, 170 and 180.

U If possible, historical data should be used to determine the range of extreme values recorded.

(b) Regulated Regime

1.* Based on the configuration of the proposed reservoirs and other relevant examples (e.g. Stikine), provide a preliminary estimate of Waddington reservoir thermal regime and reservoir release temperatures. It is assumed that reservoir modelling will not be carried out at this time, and assumptions on reservoir release temperatures will be made for downstream modelling purposes. Average and possible extreme conditions should be provided.

2.* Using the simulated reservoir release flows and estimated reservoir release temperatures, route the regulated temperatures down the lower Homathko. Provide simulated regulated daily water temperatures for the mainstem portion of the lower Homathko cross sections listed above.

3.U The reservoir release flows used in the previous study item will be based on a mean monthly target turbine flow. As part of the watershed hydrology study, some preliminary estimates of daily operating regime based on various operating scenarios will be provided. If possible, these specific daily flows should be run through the temperature model, to determine if such flow fluctuations would significantly affect water temperatures.

4.* Using the water temperatures predicted for the natural and regulated conditions, compute the accumulated number of degree-days. Degree-days should be accumulated commencing 1 August until end of November, with increments of 2 weeks until 800, 900, 1000, 1100 and 1200 degree-days are reached. Note that a composite year using all 1983 data should be used.

5.P Provide a preliminary assessment of the reliability of simulated temperature data and its sensitivity to various input
*| values and assumptions. Provide recommendations for further studies and data collection to refine and improve the simulated temperatures.

One aspect which is likely to require attention in the future, is the relationship between mainstem and secondary channel temperatures. The secondary channels often have independent water sources (hillslope flow, groundwater) and appear to be heavily used by spawning and rearing fish. This complex relationship between mainstem and secondary channel temperatures will have to be studied if significant mainstem temperature changes are predicted for the regulated regime.
*| Provide recommendations on how this problem may be addressed.

5.0 REFERENCES

1. Alderdice, D.F. and Velsen, P.J. 1978. Relation between temperature and incubation time for eggs of chinook salmon. Journal Fisheries Research Board. V35. P. 69-75.

2. HGPD, B.C. Hydro. 1981. Kootenay River Diversion Project, temperature regime studies. HGPD Report No. H 1360.

3. HGPD, B.C. Hydro. 1982. DUPSERT a program for analyzing water temperatures in one dimensional unsteady flow. HGPD Report No. H 1484.

4. Morse, W.L. 1970. Stream temperature prediction model. Water Resources Research V6-1. P. 290-302.

5. Morse, W.L. 1972. Stream temperature prediction under reduced flow. Proceedings of the American Society of Civil Eng. Vol. 98 HY 6, June 1972. P. 1031-1047.

6. Theurer, F.D. and Voos, K.A. 1983. Instream water temperature model. Co-operative Instream Flow Service Group U.S. Fish and Wildlife Service, Ft. Collins, Colorado. Info. Paper 16. 263 pp.

7. Water Resources Engs. Inc. 1970. An assessment of the temperature of releases from Libby Dam by computer simulation, Water Resources Eng. Inc., California.

ATTACHMENT 2

COMPUTER FILES

PRELIMINARY

TABLE AT2-1

COMPUTER PROGRAMS

Program File	Function
Y.YE.XKJH(DUPSERT3)	Source code for the "coupled" unsteady-flow temperature model "DUPSERT". See HGPD Report H 1484 (under preparation) for full details on model operation. Program dimensions modified to allow 1 year of data to be run.
Y.YE.XKJ.PGMLIB(DUPSERT3)	Object Code for running the "DUPSERT" Model.
Y.YE.XKJ.HOMATHKO.DEGDAYS.PROGRAM	Program for computing a series of degree-day accumulations over winter (1 August-31 July) with the start date advancing in 14-day intervals.
Y.YE.XKJH(CQTF83)	Program to merge individual files of discharge and water temperature data in "DUPSERT" format into a tributary inflow data block for use in "DUPSERT" runs.
Y.YE.XKD.CQTF82	Similar program is CQTF83 for 1982 runs.
Y.YE.XKJH(WSCTOBCH)	Program to convert discharge files from Water Survey of Canada format to "DUPSERT" format.
Y.YE.X49.Q1PULL	Program for extracting single column of output discharges or temperatures for 1 station from "HOMTEMP" output files.
Y.YE.X49.SOLRAD	Program to calculate incident solar radiation on a flat surface. Program is based on work of Raphael[11] as systematized by Thackston and Parker.[12] Program was developed by L.J. Parmley of HGPD's Hydrology Section.

TABLE AT2-1 - (Cont'd)

Program File	Function
Y.YE.X49.SAS1(HRRELHUM)	Program developed by Larry Sharp of Computer Sciences to process and tabulate hourly relative humidity data.
Y.YE.X49.SAS1(WINDSPDR)	Program developed by Larry Sharp of Computer Sciences to process and tabulate hourly wind speed and direction.
Y.YE.X49.SAS1(HRTEMP)	Program developed by Larry Sharp of Computer Sciences to process and tabulate hourly dry bulb (air) temperatures.
Y.YE.X49.SAS1(HRSOLAR)	Program developed by Larry Sharp of Computer Sciences to compute hourly dew point temperatures from dry bulb temperatures and relative humidity.
Y.YE.XKJH(SOLRAD2)	Reads in cloud cover off file "Y.YE.XKJ.VAN" and observed solar data from bottom of file. Calculates clear sky solar radiation and modifies with albedo and $(1-.0071CC^2)$ for cloud cover. Prints out % difference between observed and calculated (modified).
Y.YE.SKJH(SOLRAD3)	Reads in cloud cover from a met data file and uses it to modify calculated solar data. Results are printed and prints into an output file for use with "DUPSERT".
Y.YE.XKJH(SOLMERGE)	Merges output from Y.YE.XKJH(SOLRAD3), into met data section of "DUPSERT" input data file.

TABLE AT2-2

"DUPSERT" INPUT AND OUTPUT FILES

Input Files	Output Files
A. NATURAL CONDITIONS	
Y.YE.XKJ.HOMATHKO.DUPSERT.NATURAL	Y.YE.XKJ.HOMATHKO.HOMTEMP.NATURAL
B. POST-PROJECT CONDITIONS	
1. Tailrace at Damsite	
a. "Mid-Range" Release Temperatures	
Y.YE.XKJ.HOMATHKO.DUPSERT.REGA Y.YE.XKJ.HOMATHKO.DUPSERT.REGB	Y.YE.XKJ.HOMATHKO.HOMTEMP.REGA Y.YE.XKJ.HOMATHKO.HOMTEMP.REGB
b. "Plus 2°C" Release Temperatures	
Y.YE.XKJ.HOMATHKO.DUPSERT.PLUS2	Y.YE.XKJ.HOMATHKO.HOMTEMP.PLUS2
c. "Minus 2°C" Release Temperatures	
Y.YE.XKJ.HOMATHKO.DUPSERT.MINUS2	Y.YE.XKJ.HOMATHKO.HOMTEMP.MINUS2
2. 2.7 km Tailrace Tunnel	
a. "Mid-Range" Release Temperatures	
Y.YE.XKJ.HOMATHKO.DUPSERT.SHORTTR.REG	Y.YE.XKJ.HOMATHKO.HOMTEMP.SHORTTR.REG
b. "Plus 2°C" Release Temperatures	
Y.YE.XKJ.HOMATHKO.DUPSERT.SHORTTR.PLUS2	Y.YE.XKJ.HOMATHKO.HOMTEMP.SHORTTR.PLUS2
c. "Minus 2°C" Release Temperatures	
Y.YE.XKJ.HOMATHKO.DUPSERT.SHORTTR.MINUS2	Y.YE.XKJ.HOMATHKO.HOMTEMP.SHORTTR.MINUS2
3. 13.2 km Tailrace Tunnel	
a. "Mid-Range" Release Temperatures	
Y.YE.XKJ.HOMATHKO.DUPSERT.LONGTR.REG	Y.YE.XKJ.HOMATHKO.HOMTEMP.LONGTR.REG
b. "Plus 2°C" Release Temperatures	
Y.YE.XKJ.HOMATHKO.DUPSERT.LONGTR.PLUS 2	Y.YE.XKJ.HOMATHKO.HOMTEMP.LONGTR.PLUS2
c. "Minus 2°C" Release Temperatures	
Y.YE.XKJ.HOMATHKO.DUPSERT.LONGTR.MINUS2	Y.YE.XKJ.HOMATHKO.HOMTEMP.LONGTR.MINUS2

TABLE AT2-3

METEOROLOGICAL DATA FILES

File	Remarks
Y.YE.X49.HOMSTND1 (formerly X.XNOO.F49.HOMSTND1)	Input data set of raw meteorological data on relative humidity, air temperature, wind run and direction in that sequence. Each record of these four items in the file contains four 2-digit fields for the year, month, day and hour plus the station number 116601 for Scar Creek.
Y.YE.XKJ.SOLAR	Input data set of observed solar radiation.

PRELIMINARY

TABLE AT2-4

MISCELLANEOUS DATA FILES

File	Remarks
Y.YE.XKD.HOTRAQ82	Discharge data for the Homathko River at Tragedy Canyon; 20 May-10 Aug. 1982.
Y.YE.XKD.HOMOUQ82	Discharge data for the Homathko River at the Mouth; 20 May-10 Aug. 1982.
Y.YE.XKJ.HOMATHKO.DEGDAYS.NAT 170	Sample input file for use with "DEGDAYS. PROGRAM" in Table AT2-1. This is for natural conditions at station XLH170.
Y.YE.XKJH(DUPS833)	DUPSERT input data set for 1983 hydraulic calibration (1 Jan.-10 Aug.) with tributuary inflow ratio #3.
Y.YE.XKJH(DUPS823)	DUPSERT input data set for 1982 hydraulic calibration (20 May-10 Aug.) with tributary inflow ratio #3.
Y.YE.X87.HTEMPB	DUPSERT input data set with original cross section and slopes for XLH10, XLH30, XLH70, XLH110, XLH120, XLH140, XLH155, XLH160.
Y.YE.X87.RCNOB	File used in numerical stability checks with a constant slope, constant cross section, no tributary discharges and a time length of 2 hours to 2 days. It was used for runs 8850, 8811, 8799 with Δt = 60 s, 1 hr, 1 day. Mainstem flow varies throughout.
Y.YE.X87.RCNOBTT	File used in numerical stability checks with a constant slope, constant cross section, no tributary inflow and a time length of 2 hours to 33 days. The mainstem flow was that for day 32 and 33 only. It was used for following runs:

Run	Δt	Length
1895	1 hr	2 hr
1939	1 min	2 hr
1871	1 hr	33 days
1862	1 day	33 days
8637	1 min	2 hr
9001	1 hr	2 hr
8552	1 hr	2 days
8591	1 day	2 days

PRELIMINARY

ATTACHMENT 3

WATER TEMPERATURE MODEL

ATTACHMENT 3
WATER TEMPERATURE MODEL

The theoretical background of the method used to analyze water temperatures in one-dimensional unsteady flow is described in the attached paper "Modeling of Unsteady-Flow Water Temperatures".[3] This paper was written to describe the development and use of the program "DUPSERT" which was used for the Homathko Development studies.

When preparing to run the model the river system to be analyzed is divided into a series of channels within which the cross section is assumed to be uniform. In the version of the model used in this study the cross section must be of a prismatic shape as shown on Fig. A3-1. Each channel is sub-divided into n reaches of equal length such that there are n + 1 sections at which discharge and temperatures conditions will be computed (Fig. A3-2).

When this model is run the initial steady state hydraulic conditions are calculated to initialize the hydraulic computations and then the initial temperatures along the river are computed using linear interpolation from given initial values. The transient hydraulic conditions at the end of the first time interval are then computed. If the computation time interval is the same for the hydraulic and temperature computations, the temperatures in the system are computed; otherwise, hydraulic computations are continued until the time is equal to the computational time interval for water temperature computations. For each time step the hydraulic computations are done first and then the temperature computations are made using the flow depths, discharges and river widths that have just been computed. As the temperature computations are done after the hydraulic computations this model is a coupled hydrodynamic and temperature model.

ATTACHMENT 3

Paper describing "DUPSERT" in May 1983 Issue of ASCE Journal of Hydraulics

Modeling of Unsteady-Flow Water Temperatures

By M. Hanif Chaudhry,[1] M. ASCE, David E. Cass,[2] and John E. Edinger,[3] M. ASCE

Abstract: A mathematical model is presented to simulate water temperatures of one-dimensional unsteady flows in a river-lake system having time-varying lateral inflows and several cross-sectional changes along its length. In the hydraulic part initial steady state conditions are computed by numerically integrating the gradually-varied flow equation using the fourth-order Runge-Kutta method and the unsteady flow conditions by integrating the one-dimensional Saint Venant equations using an implicit finite difference method. An upwind implicit finite difference scheme is used to solve the partial differential equation governing the water temperature of unsteady flows. Comparison of the computed water temperatures with those measured on the Columbia and Kootenay Rivers show good agreement.

Introduction

A mathematical model was developed to simulate water temperatures of unsteady flows in a river system having time-varying lateral inflows and several cross-sectional changes along its length. In order to make the model suitable for computation of water temperatures for several months using a computational time interval of 6 hr–24 hr, computational procedures were selected so that the computer time was minimal without adversely affecting the accuracy of the results. These computational procedures are different from those of similar mathematical models presented earlier (1,2,14).

This paper summarizes the governing equations, numerical methods used for their solution and comparison of the computed and measured results for the verification of the mathematical model. The results of studies conducted to assess the effects of the diversion of cooler waters of the Kootenay River into the Columbia River are also presented.

Mathematical Model

The mathematical model is comprised of two parts: hydraulic and water temperature. A brief description of each follows.

[1]Assoc. Prof., Dept. of Civ. Engrg., Old Dominion Univ., Norfolk, Va.
[2]Engr., Development Dept., British Columbia Hydro and Power Authority, Vancouver, British Columbia, Canada.
[3]Edinger and Assoc., Wayne, Pa.

Note.—Discussion open until October 1, 1983. To extend the closing date one month, a written request must be filed with the ASCE Manager of Technical and Professional Publications. The manuscript for this paper was submitted for review and possible publication on March 17, 1982. This paper is part of the Journal of Hydraulic Engineering, Vol. 109, No. 5, May, 1983. ©ASCE, ISSN 0733-9429/83/0005-0657/$01.00. Paper No. 17936.

Hydraulic.—In the hydraulic part the initial steady-state conditions and then the unsteady flow conditions are computed. These conditions include flows, flow velocities, and flow depths. The model may be used for the analysis of rivers, lakes, and reservoirs in which the assumptions of one-dimensional flows and uniform velocity distribution over each channel cross section are valid. Time-varying lateral inflows either distributed along the channel or concentrated at point locations as tributaries may be specified. There may be cross-sectional changes along the channel length. The following boundary conditions may be included: (1) At the upstream end, a constant-level reservoir or a time-varying discharge; and (2) at the downstream end, a constant-level reservoir, a rating curve, or a time-varying discharge.

The steady-state flow conditions are computed by numerically integrating the following one-dimensional, gradually-varied flow equation (5,8) using the fourth-order Runge-Kutta method (4,9,14):

$$\frac{dy}{dx} = \frac{S_o - S_f - \frac{2qQ}{gA^2}}{1 - \frac{Q^2 B}{gA^3}} \quad \ldots\ldots (1)$$

in which y = flow depth; x = distance measured along the channel bottom, positive in the downstream direction; S_o = channel bottom slope; S_f = slope of energy grade line; Q = flow; q = distributed lateral inflow (inflows are considered positive and outflows as negative); A = channel cross-sectional area; B = top water-surface width; and g = acceleration due to gravity.

The unsteady-flow conditions are computed by numerically integrating the St. Venant equations (4,16):

1. Continuity equation:

$$\frac{\partial Q}{\partial x} + B\frac{\partial y}{\partial t} - q = 0 \quad \ldots\ldots (2)$$

2. Momentum equation:

$$\frac{\partial Q}{\partial t} + 2V\frac{\partial Q}{\partial x} + gA(1 - F^2)\frac{\partial y}{\partial x} = gA(S_o - S_f) - gAD_1 + qV \quad \ldots\ldots (3)$$

in which t = time; V = average flow velocity; F = Froude number = $V/\sqrt{gA/B}$; and D_1 = dynamic contribution of the lateral inflow [for lateral inflow perpendicular to the main channel, $D_1 = qV/(gA)$].

The implicit finite-difference method presented by Strelkoff (4,16) is used herein to solve Eqs. 2 and 3 subject to specified boundary conditions. In this method the partial derivatives of the governing equations are replaced by finite-difference quotients as follows:

$$\frac{\partial Q}{\partial x} = \frac{Q_{i+1}^{j+1} - Q_{i-1}^{j+1}}{2\Delta x} \quad \ldots\ldots (4)$$

$$\frac{\partial y}{\partial t} = \frac{y_i^{j+1} - y_i^j}{\Delta t} \quad \ldots\ldots (5)$$

$$\frac{\partial Q}{\partial t} = \frac{Q_i^{j+1} - Q_i^j}{\Delta t} \quad \ldots\ldots (6)$$

$$\frac{\partial y}{\partial x} = \frac{y_{i+1}^{j+1} - y_{i-1}^{j+1}}{2\Delta x} \quad \ldots\ldots (7)$$

in which subscripts i, $i-1$ and $i+1$ refer to channel sections in the x-direction and the superscripts j and $j+1$ refer to the time grid (Fig. 1). Conditions are known at time t_o (line j) and they are to be computed at time $t_o + \Delta t$ (line $j+1$). All coefficients in the governing equations are computed at time t_o except the friction slope which is evaluated at time $t_o + \Delta t$, i.e.

$$S_{f_i}^{j+1} = \frac{Q_i^{j+1}|Q_i^{j+1}|}{(K_i^{j+1})^2} \quad \ldots\ldots (8)$$

in which $K_i^{j+1} = 1/n\, A\, R^{2/3}|_{y = y_i^{j+1}}$ if Manning's formula in the SI system is used. If S_{f_i} at time t_o is also used, then the resulting scheme is not unconditionally stable. However, if the previous expression for S_{f_i} is used, then the resulting algebraic equations will be nonlinear. To avoid this, Eq. 8 may be linearized as

$$S_{f_i}^{j+1} \simeq S_{f_i}^{j} + \left.\frac{\partial S_f}{\partial Q}\right|_i^j (Q_i^{j+1} - Q_i^j) + \left.\frac{\partial S_f}{\partial K}\right|_i^j \left.\frac{\partial K}{\partial y}\right|_i^j (y_i^{j+1} - y_i^j) \quad \ldots\ldots (9)$$

Note that $\partial S_f/\partial Q$ and $\partial S_f/K$ are evaluated at time t_o and the expressions for these derivatives may be obtained by differentiating Eq. 8.

Replacing the partial derivatives of Eqs. 2 and 3 by the finite differences listed in Eqs. 4–7, replacing S_f of Eq. 3 by the expression given in Eq. 9, substituting expressions for $\partial S_f/\partial Q$ and $\partial S_f/\partial K$ and simplifying the resulting equations

$$a_i Q_{i+1}^{j+1} - a_i Q_{i-1}^{j+1} + b_i y_i^{j+1} = C_i \quad \ldots\ldots (10)$$

$$e_i Q_{i+1}^{j+1} + f_i Q_i^{j+1} - e_i Q_{i-1}^{j+1} + k_i y_{i+1}^{j+1} + l_i y_i^{j+1} - k_i y_{i-1}^{j+1} = D_i \quad \ldots\ldots (11)$$

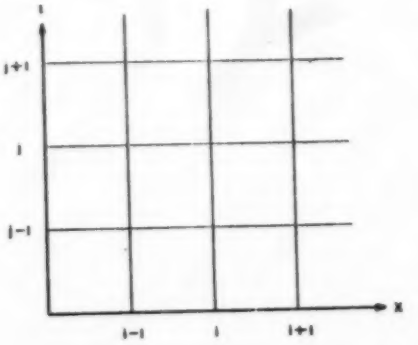

FIG. 1.—Definition Sketch for Implicit Scheme

in which $a_i = (1/2)\Delta x$; $b_i = B_i^j/\Delta t$; $C_i = B_i^j y_i^j/\Delta t + q$; $e_i = V_i^j/\Delta x$; $f_i = (2gA_i^j S_{f_i}^j/Q_i^j) + 1/\Delta t$; $k_i = 1/2\,(gA_i^j - B_i^j V_i^{j2})/\Delta x$; $l_i = -2gS_{f_i}^j A_i^j (dK/dy)_i^j/K_i^j$; and $D_i = gA_i^j\{S_o + S_{f_i}^j[1 - 2y_i(dK/dy)_i^j/K_i^j]\} + Q_i^j/\Delta t + V_i^j q - qV_i^j$.

For the upstream boundary, the negative characteristic equation may be written as

$$a_1 Q_1^{j+1} + b_1 Q_2^{j+1} + e_1 y_1^{j+1} + f_1 y_2^{j+1} = D_1 \quad \ldots\ldots (12)$$

in which $a_1 = (1/\Delta t) + (2gA_1 S_{f_1}^j/Q_1^j) - (V_1 - c_1)/\Delta x$; $b_1 = (V_1^j - c_1^j)/\Delta x$; $e_1 = -(V_1 + c_1)\,B_1/\Delta t + (V_1^{j2} - c_1^{j2})\,B_1^j/\Delta x - 2gA_1^j S_{f_1}(dK/dy)_1^j/K_1^j$; $f_1 = -(V_1^{j2} - c_1^{j2})B_1^j/\Delta x$; and $D_1 = gA_1^j\{S_o + S_{f_1}^j[1 - 2y_1^j(dK/dy)_1^j/K_1^j]\} + Q_1^j/\Delta t - (V_1^j + c_1^j)\,B_1^j y_1^j/\Delta t - V_1^j q - c_1^j q$. In addition, the conditions imposed by the upstream boundary may be written in a generalized form as

$$e_1 Q_1^{j+1} + f_1 y_1^{j+1} = J_1 \quad \ldots\ldots (13)$$

If the conditions imposed by the boundary are nonlinear, these may be linearized, in segments if necessary, and expressed in the preceding form. For example, in this study, flows were specified at the upstream boundary. Therefore, $e_1 = 1$, $f_1 = 0$ and J_1 = specified flow at the end of the time step.

Proceedings similarly for the downstream boundary at section $n + 1$, the positive characteristic equation may be written as

$$a_{n+1} Q_n^{j+1} + b_{n+1} Q_{n+1}^{j+1} + e_{n+1} y_n^{j+1} + f_{n+1} y_{n+1}^{j+1} = D_{n+1} \quad \ldots\ldots (14)$$

in which $a_{n+1} = -(V_{n+1}^j + c_{n+1}^j)/\Delta x$; $b_{n+1} = (2gA_{n+1}^j S_{f_{n+1}}^j/Q_{n+1}^j) + (V_{n+1}^j + c_{n+1}^j)/\Delta x + 1/\Delta t$; $e_{n+1} = (V_{n+1}^{j2} - c_{n+1}^{j2})\,B_{n+1}^j/\Delta x$; $f_{n+1} = -(V_{n+1}^j - c_{n+1}^j)B_{n+1}^j/\Delta t - (V_{n+1}^{j2} - c_{n+1}^{j2})\,B_{n+1}^j/\Delta x - 2gA_{n+1}^j S_{f_{n+1}}^j (dK/dy)_{n+1}/K_{n+1}$; and $D_{n+1} = gA_{n+1}\{S_o + S_{f_{n+1}}^j[1 - 2y_{n+1}^j(dK/dy)_{n+1}^j/K_{n+1}^j]\} + Q_{n+1}^j/\Delta t - (V_{n+1}^j - c_{n+1}^j)\,B_{n+1}^j y_{n+1}^j/\Delta t + c_{n+1}^j q - V_{n+1}^j q$. The conditions imposed by the downstream boundary may be written as

$$e_{n+1} Q_{n+1}^{j+1} + f_{n+1} y_{n+1}^{j+1} = J_{n+1} \quad \ldots\ldots (15)$$

If a channel is divided into n reaches, there are $(n + 1)$ sections. Since each section has two unknowns, namely flow and flow depth, there will be $2(n + 1)$ unknowns. Thus, as many equations must be available for obtaining a unique solution. Two equations (Eqs. 12 and 13) are provided by the upstream boundary; two other equations (Eqs. 14 and 15) are given by the downstream boundary, while two more equations (Eqs. 10 and 11) are written for each of the $(n - 1)$ interior sections. Thus, a unique solution can be obtained for each time step. These equations for a system may be written in matrix notation as

$$\mathbf{Ax} = \mathbf{b} \quad \ldots\ldots (16)$$

in which $\mathbf{A}$ = the coefficient matrix; $\mathbf{x}$ = the column vector comprised of the unknown quantities Q and y; and $\mathbf{b}$ = a column vector comprised of the constants on the right-hand side of Eqs. 10–15. Since $\mathbf{A}$ is a banded matrix, special standard computer subroutines may be used to save computer time as well as storage requirements.

Water Temperature.—The water temperature of one-dimensional flows may be determined by solving the following equation (7):

$$\frac{\partial(AT)}{\partial t} + \frac{\partial(QT)}{\partial x} - \frac{\partial}{\partial x}\left(AD\frac{\partial T}{\partial x}\right) = -Bk(T - E) + qT_l \quad \ldots\ldots (17)$$

in which T = cross-sectional averaged water temperature; D = longitudinal dispersion coefficient; k = surface-heat-exchange coefficient; T_l = temperature of distributed lateral inflows; and E = equilibrium temperature. It is assumed the lateral inflows mix instantaneously with the flows in the main river channel thus producing a uniform water temperature over the cross section.

The coefficient of surface heat exchange, K, and the equilibrium temperature, E, are computed from the term by term heat budget of surface heat exchange using the meteorological data of shortwave solar radiation, air temperature, dew point temperature, and wind speed following the methods given previously (7). Use of the coefficient, K allows the water temperature dependent terms of surface heat exchange to be taken forward in time for implicit solution on the day of computation. The five meteorological variables are preprocessed to the time-varying inputs of K and E which reduces extensive iterative computation on each time step of the temperature computations. The dispersion coefficient, D, may be computed by using the procedure obtained in Ref. 2.

For an implicit formulation (3,13,15), various terms in Eq. 17 may be replaced as follows:

$$\frac{\partial(AT)}{\partial t} = \frac{A_i^{j+1}T_i^{j+1} - A_i^j T_i^j}{\Delta t} \quad \ldots\ldots (18)$$

$$\frac{\partial}{\partial x}\left(AD\frac{\partial T}{\partial x}\right) = [0.5(A_{i+1}^{j+1} + A_i^{j+1})\,D_i^{j+1}(T_{i+1}^{j+1} - T_i^{j+1})$$

$$- \frac{0.5\,D_{i-1}^{j+1}(A_i^{j+1} + A_{i-1}^{j+1})(T_i^{j+1} - T_{i-1}^{j+1})]}{(\Delta x)^2} \quad \ldots\ldots (19)$$

$$Bk(T - E) = B_i^{j+1}k^{j+1}T_i^{j+1} - B_i^{j+1}k^{j+1}E_i^{j+1} \quad \ldots\ldots (20)$$

$$qT_l = q_i^{j+1}T_{l_i}^{j+1} \quad \ldots\ldots (21)$$

"Upwind" finite differences are used as follows for the advective-transport term to avoid severe restriction on Δx for stability. The average flows at sections i and $i - 1$ may be defined as

$$\left.\begin{aligned}\bar{Q}_i^{j+1} &= \frac{1}{2}(Q_{i+1}^{j+1} + Q_i^{j+1})\\ \bar{Q}_{i-1}^{j+1} &= \frac{1}{2}(Q_i^{j+1} + Q_{i-1}^{j+1})\end{aligned}\right\} \quad \ldots\ldots (22)$$

An "upwind" operator α_i^{j+1} is introduced such that α_i^{j+1} is equal to zero for $\bar{Q}_i^{j+1} < 0$ and equal to 1 for $\bar{Q}_i^{j+1} > 0$. The advective term then becomes

$$\frac{\partial(QT)}{\partial x} = \frac{\bar{Q}_i^{j+1}[T_i^{j+1}\alpha_i^{j+1} + T_{i+1}^{j+1}(1 - \alpha_i^{j+1})] - \bar{Q}_{i-1}^{j+1}[T_{i-1}^{j+1}\alpha_{i-1}^{j+1} + T_i^{j+1}(1 - \alpha_{i-1}^{j+1})]}{\Delta x} \quad \ldots\ldots (23)$$

Making these substitutions into Eq. 17 and simplifying, one obtains

$$a_i T_{i-1}^{j+1} + b_i T_i^{j+1} + c_i T_{i+1}^{j+1} = f_i \quad \ldots\ldots (24)$$

in which $a_i = -\frac{\hat{Q}_{i-1}^{t+1}\alpha_{i-1}^{t+1}}{\Delta x} - \frac{(A_i^{t+1} + A_{i-1}^{t+1})\, D_{i-1}^{t+1}}{2(\Delta x)^2}$ ..... (25)

$$b_i = \frac{A_i^{t+1}}{\Delta t} + B_i^{t+1}k^{t+1} + \frac{(A_{i+1}^{t+1} + A_i^{t+1})\, D_i^{t+1}}{2(\Delta x)^2}$$
$$+ \frac{(A_i^{t+1} + A_{i-1}^{t+1})\, D_{i-1}^{t+1}}{2(\Delta x)^2} + \frac{Q_i^{t+1}\alpha_i}{\Delta x} - \frac{\hat{Q}_{i-1}^{t+1}(1 - \alpha_{i-1}^{t+1})}{\Delta x} \quad \text{..... (26)}$$

$$c_i = \frac{\hat{Q}_i^{t+1}(1 - \alpha_i)}{\Delta x} - \frac{(A_{i+1}^{t+1} + A_i^{t+1})\, D_i^{t+1}}{2(\Delta x)^2} \quad \text{..... (27)}$$

$$f_i = \frac{A_i T_i}{\Delta t} + k^{t+1}B_i^{t+1}E^{t+1} + qT_i^{t+1} \quad \text{..... (28)}$$

The average flow $\hat{Q}_i^{t+1}$ may be readily computed from the known hydraulic information at sections i and $i + 1$ and then the value of α_i^{t+1} is selected when $\hat{Q}_i^{t+1}$ is known.

Note that coefficients b_i are always positive, and a_i and c_i are always negative. The scheme is, therefore, unconditionally stable.

The numerical computations at each channel section are performed as follows: Determine A_i^{t+1}, B_i^{t+1}, and Q_i^{t+1} from hydraulic computations for time $t_o + \Delta t$ and compute D_i^{t+1} and α_i^{t+1}. Re-evaluate lateral inflows from continuity to be compatible with the averaged $\hat{Q}_i^{t+1}$ as

$$q_o = \frac{A_i^{t+1} - A_i^t}{\Delta t} + \frac{\hat{Q}_i^{t+1} - \hat{Q}_{i-1}^{t+1}}{\Delta x} \quad \text{..... (29)}$$

If the adjusted value of lateral inflow, q_o, is different from q, then the temperature, T_i, of the lateral inflow is changed to qT_i/q_o to account for the adjustment in the value of q to satisfy continuity conditions. Determine k^{t+1} and E^{t+1} from the known meterological conditions for dew point, cloud cover, air temperature, wind speed, and from the computed values of solar and atmospheric radiation. Compute coefficients a_i, b_i, c_i, and d_i, and solve Eq. 24 for T_i^{t+1}.

Mathematical Model

The variation of water temperatures with time at the upstream boundary was specified while zero temperature gradient was assumed at the downstream boundary and a sufficient length of a hypothetical channel was added to avoid affecting the results in the main channel.

The steady-state hydraulic conditions were computed starting at the downstream end and then the initial water temperatures along the river length were linearly interpolated from the water temperatures specified at given locations. The transient state hydraulic conditions at the end of the first computational time step were then computed. If the size of computational time interval for the hydraulic and temperature computations was the same, water temperatures in the system were computed; otherwise, hydraulic computations were continued until the time was equal to the computational time interval for water-temperature computations.

This procedure was repeated until conditions were computed for the required time span.

Verification of Mathematical Model

To verify the mathematical model, water temperature data on the Columbia and Kootenay Rivers (Fig. 2) measured during 1977 through 1979 were used (6,10,11,12). To conserve space, only investigations for the Columbia River are summarized in this section.

The available data for 19 channel cross sections were used for the Columbia and Windermere lakes and for the river channel between the two lakes. Hydraulic computations were based on the water levels and discharges reported by the Water Survey of Canada at their gaging stations at Fairmont and Athalmer. Dutch Creek flows were assumed to be 77% of the known flows at Fairmont based on the ratio of the drainage area of Dutch Creek to that of the Columbia River at Fairmont. Water temperatures for the local inflows between Columbia and Windermere Lakes were taken as equal to those recorded on Dutch Creek. Water temperatures for the missing periods in the records for Dutch Creek were estimated by correlation with the temperatures recorded on neighboring tributaries.

Meterological data recorded at the Cranbrook airport was used for this study. Although Cranbrook is 70 km south of the project area, it is the nearest station where hourly data on air temperature, dew point, wind speed, and cloud cover are recorded. Based on the results of verification tests, Cranbrook air temperatures were decreased by 2° C to account for differences in the various meteorological conditions between the project site and Cranbrook airport.

Net absorbed shortwave solar radiation for the project site computed from the equation presented by Parker (17), using coefficients for a latitude of 50°, 30' N was compared with the total incoming shortwave radiation measured at the project site and at another interior British Columbia location. Before making the comparison corrections of 7% for the albedo of water surface and 1.5% for the shading effect of the surrounding north-south ranges of mountains were applied to adjust for the difference between the total incoming and the net radiation. The albedo correction was based on Fig. 2-1 (*f*) of Ref. 7 and the shading correction was estimated from a shading diagram drawn by Tuller (18) together with the hourly distribution of shortwave radiation given by Hay (8). Both of these comparisons indicated that Parker's equation overestimated the shortwave radiation by 5%–6%. Thus, a correction of −6% was applied.

Overall, there was good agreement between the measured and computed water temperatures at almost all locations. To conserve space only comparisons at three locations are presented in Figs. 3–5. There was also very good agreement between the shapes of the computed and measured traces. The two exceptions were at Columbia B in 1978 and Columbia Mid in 1979 where differences between the computed and measured water temperatures were +2° C and −2° C, respectively. These two stations are in the northern end of Columbia Lake where the cold waters of Dutch Creek mix with the warm lake waters. Two-dimensional

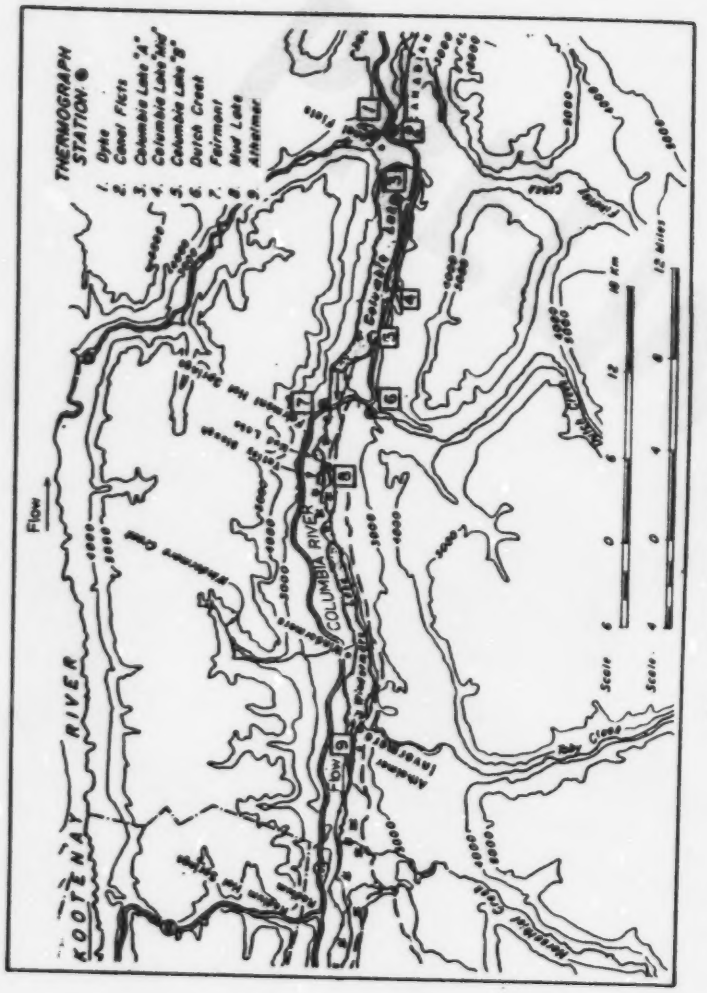

FIG. 2.—Study Area and Thermograph Locations

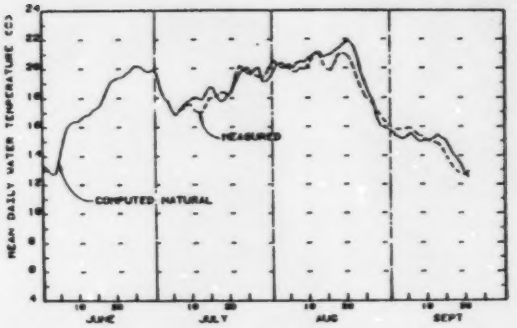

FIG. 3.—Comparison of Computed and Measured Water Temperatures at Columbia B

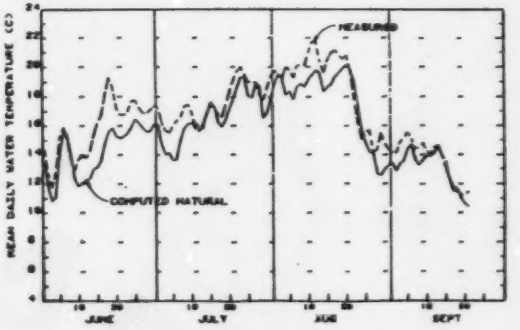

FIG. 4.—Comparison of Computed and Measured Water Temperatures at Fairmont

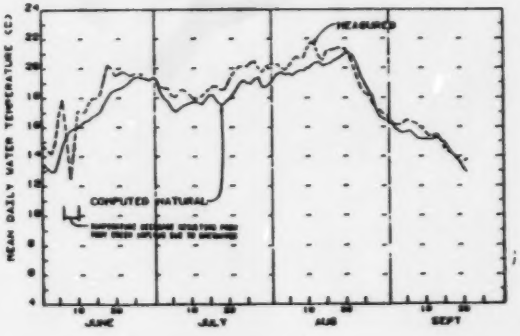

FIG. 5.—Comparison of Computed and Measured Water Temperatures at Athalmer

studies (6) of three typical steady state flow conditions in this area showed that flow from Dutch Creek does circulate back into Columbia Lake resulting in a two-dimensional flow pattern. These circulation patterns are strongest between the lake outlet and Columbia B but also extend as far south as Columbia Mid. Since the mathematical model is based on the assumption of one-dimensional flow it cannot properly predict natural conditions in the area of most intense circulation between Columbia B and the lake outlet. However, by proportioning the flow of Dutch Creek along the side of Columbia Lake between the outlet and Columbia Mid it was possible to preserve the mass and heat balance of this region as a whole. This was demonstrated by the good agreement between the computed and measured results.

Post-Diversion Results

In the Kootenay River Diversion Project, British Columbia, Canada, it is envisaged that water from the Kootenay River at Canal Flats will be diverted into Columbia Lake (Fig. 2) to increase flows for power generation at the existing or future hydroelectric power plants located on the Columbia River. The water in the Kootenay River is usually 3.5° F–9° F cooler during the summer than that in the Columbia River from Columbia Lake to Athalmer (Fig. 2). Since this reach of the river is heavily used by tourists for swimming, boating, and other recreational activities, the effects of this diversion on the temperature regime of the Columbia River were determined.

For this purpose, computed pre-diversion and post-diversion water temperature were compared (Figs. 6–8). Pre-diversion temperatures were computed for the known lateral inflows, their temperatures and known meteorological conditions. For the post-diversion conditions, specified amount of flows having known temperatures were introduced at the upstream end of Columbia Lake which were assumed to mix instantaneously thus producing a uniform water temperature over the cross section at the entrance. Lateral inflows and meteorological conditions were the same as for the pre-diversion conditions.

The purpose of computing the pre-diversion water temperatures was two-fold: (1) Data will be available at all locations in the system for the pre-diversion conditions thus eliminating periods during which water temperatures were not recorded due to equipment malfunction or vandalism; and (2) any anomalies in the input data will be automatically taken care of.

In the very north end of Columbia Lake an interesting anomaly appeared in some years whereby the post-diversion temperature would have at times been 2° F–7° F (1° C–4° C) warmer than the pre-diversion temperatures. In the pre-diversion case, the cold waters of Dutch Creek significantly lower the temperatures in the very north end of Columbia Lake due to back circulation. In the post-diversion case this back-circulation of flows from Dutch Creek is prevented by the high flows moving down the lake. In addition, the diversion flows warm significantly as they travel approximately 8 mile (13 km) down Columbia Lake and near the north end of the lake may be warmer than the Dutch Creek inflows. Since diversion flows of 2,800 cfs–5,300 cfs (80 m^3/sec–150 m^3/

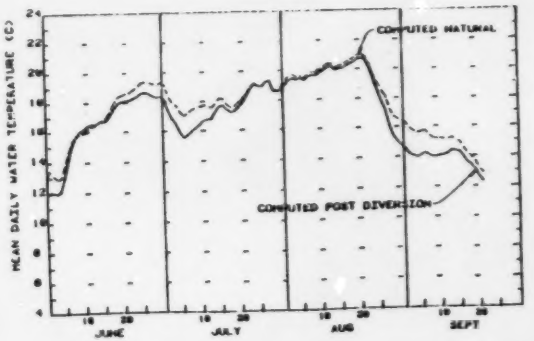

FIG. 6.—Comparison of Pre- and Post-Diversion Water Temperatures at Columbia B

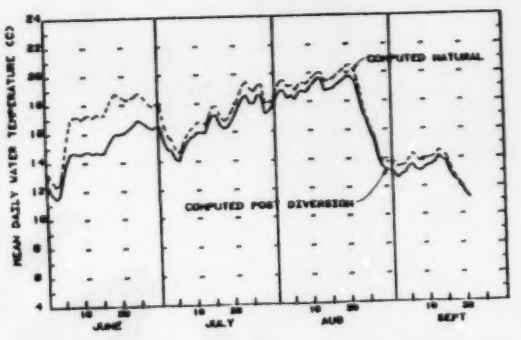

FIG. 7.—Comparison of Pre- and Post-Diversion Water Temperatures at Fairmont

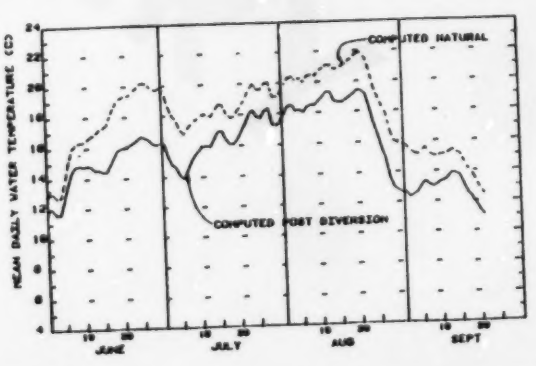

FIG. 8.—Comparison of Pre- and Post-Diversion Water Temperatures at Athalmer

sec) are significantly greater than the Dutch Creek flows of 700 cfs–1,100 cfs (20 m^3/sec–30 m^3/sec), the impact of Dutch Creek Flows on water temperatures is much less during post-diversion than during pre-diversion conditions.

Acknowledgments

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Appendix II.—Notation

The following symbols are used in this paper:

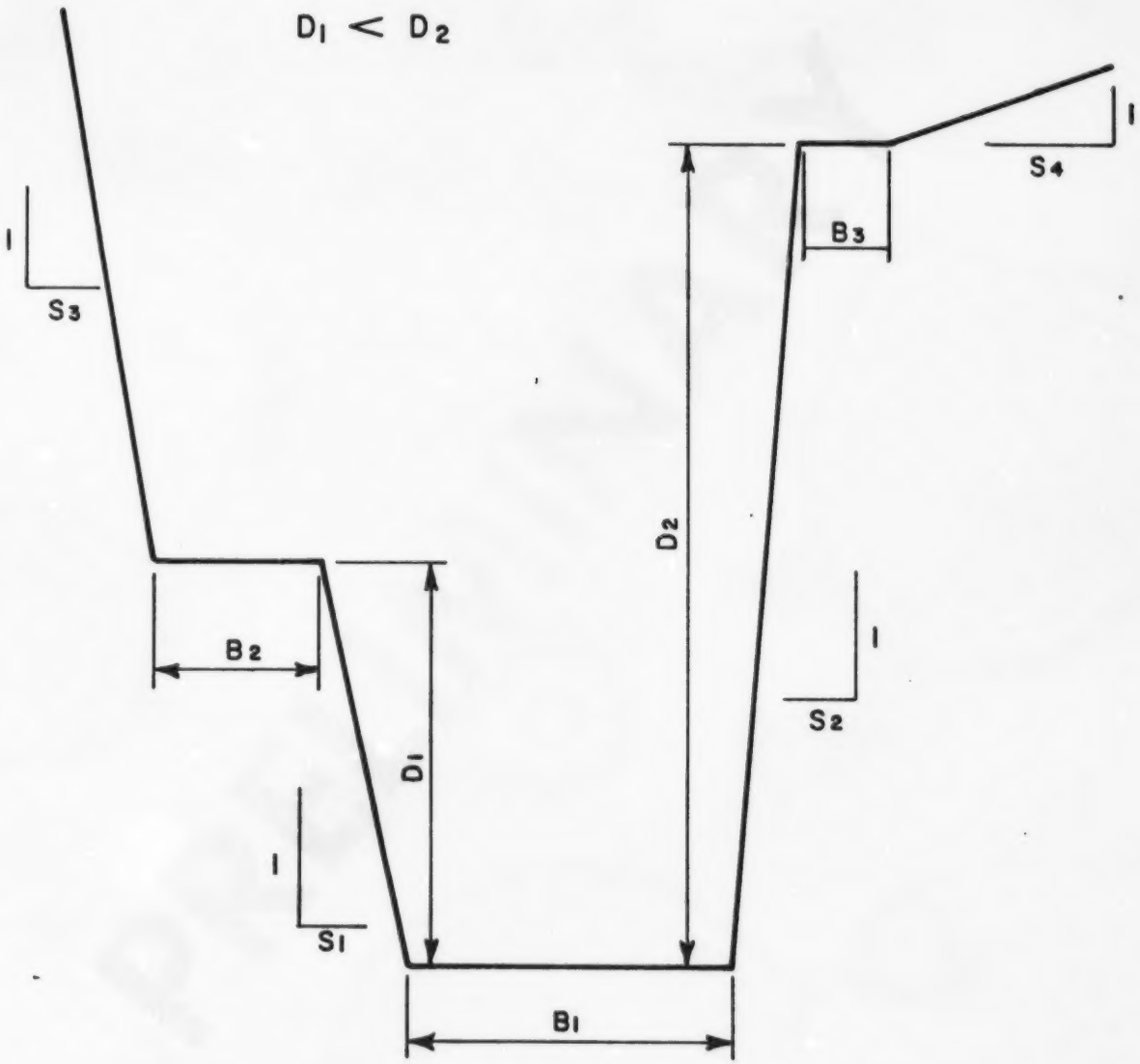
a_1, a_i, a_{n+1} = coefficients in Eqs. 10–14, 24, and 25;
A = channel cross-sectional area, coefficient matrix in Eq. 16;
$\mathbf{A}$ = matrix in Eq. 16;
B = top water-surface width;
b_1, b_i = coefficients in Eqs. 10–14, 24, and 26;
c_i = coefficients in Eqs. 10, 24, and 27;
D = longitudinal dispersion coefficient;
D_l = dynamic contribution of lateral inflow = $qV/(gA)$, coefficient;
E = equilibrium temperature in Eq. 12;
e_1, e_i = coefficients in Eqs. 11–14;
F = $V/\sqrt{(gA/B)}$ = Froude number;
f_i = coefficients in Eqs. 11–14, 24, and 28;
g = acceleration due to gravity;
K = conveyance factor = $AR^{2/3}/n$;
k = surface-heat-exchange coefficient;
Q = flow;
q = distributed lateral inflow;
S_f = slope of energy grade line;
S_o = channel bottom slope;
T = cross-sectional averaged water temperature;
T_l = temperature of lateral inflow;
t = time;
V = flow velocity;
x = distance along channel measured positive in downstream direction;
$\mathbf{x}$ = column vector in Eq. 16;
y = flow depth;
α = upwind operator;
Δt = computational time interval; and
Δx = channel reach length.

Subscripts and Superscripts

$i, i-1, i+1, n, n+1$ = channel-section number; and
$j, j-1, j+1$ = refer to time.

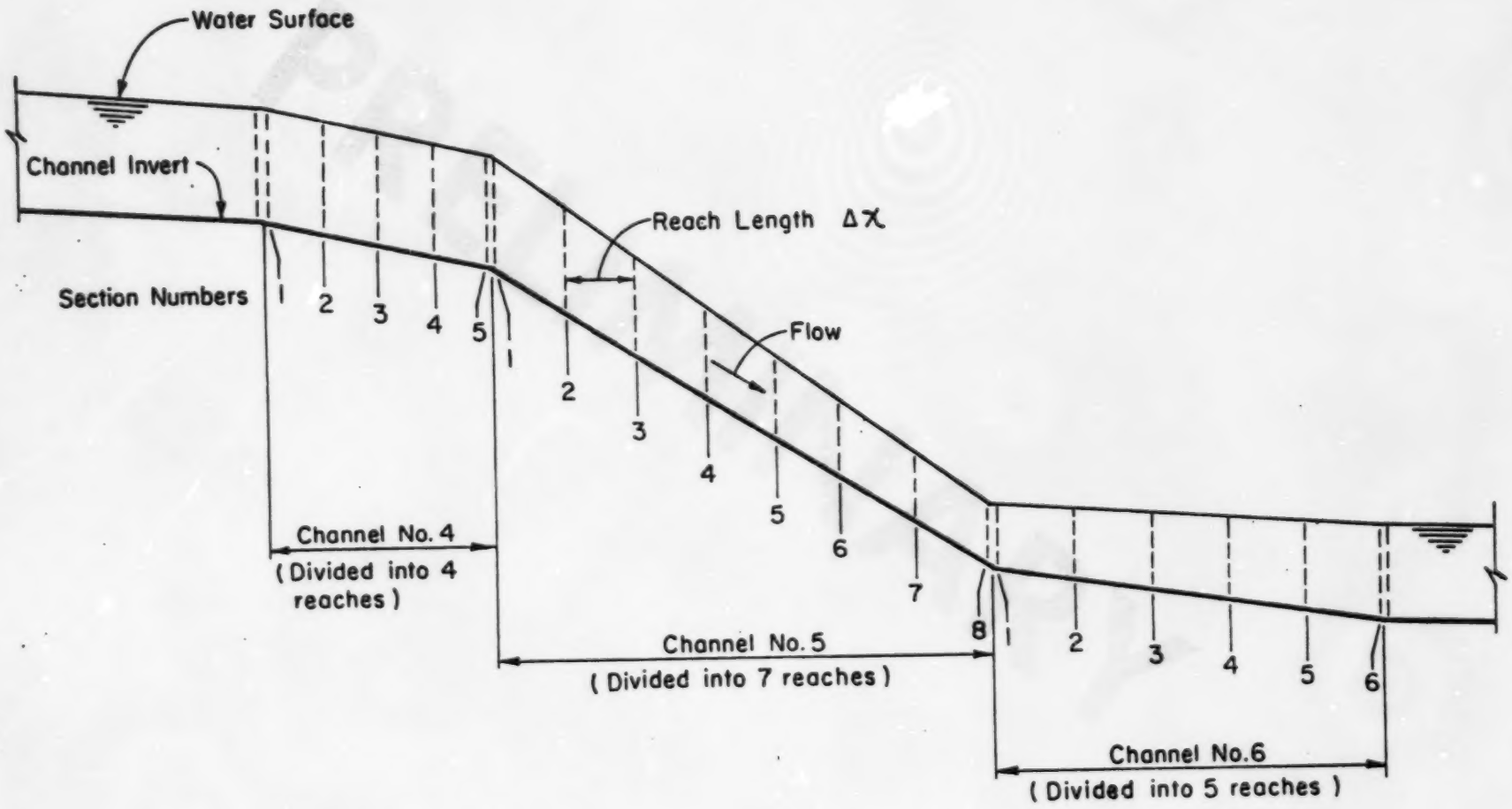
$$S = \frac{\Delta L}{\Delta H}$$

$D_1 < D_2$



NOTATION FOR A
TYPICAL CROSS-SECTION

FIG. A3-1



MODEL REPRESENTATION OF A RIVER

FIG. A3 – 2